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Ekológia (Bratislava) - Journal of the Institute of Landscape Ecology, Slovak Academy of Sciences Vol. 43, No. 2, p. 158–166, 2024

DOI:10.2478/eko-2024-0016

ASSESSMENT OF THE HEALTH STATUS OF OAK TREES IN THE ZOUAGHA FOREST (NORTH-EAST OF ALGERIA)

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Received: 5 April 2024 / **Accepted:** 29 July 2024

Abstract

Choutier N., Rached-Kanouni M., El Wahida Boucif O.: Assessment of the health status of oak trees in the Zouagha forest (north-east of Algeria). Ekológia (Bratislava), Vol. 43, No. 2, p. 158–166, 2024.

The objective of this study is to assess the health status of the Zouagha forest in Algeria, which is composed of oak trees (*Quercus suber*, *Q. canariensis*, and *Q. afares*), and to estimate its biodiversity potential through field observations using the ARCHI, DEPEFEU, and IBP methods on individuals of each species. The adopted methodology relies on a visual evaluation of the tree crowns of the main species in this forest. The results indicate that the health of tree crowns is moderate, as is the biodiversity carrying capacity according to the IBPrating scale. Within the ARCHI protocol, two distinct types can be observed: ARCHI type R (Resilient), characterized by proportions of 42.72% for *Q. suber*, 40.7% for *Q. canariensis*, and 45% for *Q. afares*, and the ARCHI type S (Healthy), with slightly different proportions, namely 38.18% for *Q. suber*, 38.05% for *Q. canariensis*, and 36% for *Q. afares*. Regarding the DEPEFEU protocol, it is important to note that the average health condition class has percentages of 37.27% for *Q. suber*, 32.74% for *Q. canariensis*, and 39% for *Q. afares*. Therefore, it is imperative to implement appropriate forest management strategies to ensure the sustainability of forest ecosystems. These strategies should aim to preserve the ecological integrity of the Zouagha forest in Algeria, with a focus on the regeneration of oak species (*Q. suber, Q. canariensis*, and *Q. afares*) and the restoration of their health.

Key words: Zouagha, oaks, decline, ARCHI, DEPEFEU, IBP.

Introduction

Over the past century, oak forests have experienced several periods of decline. The appearance and growth of trees are subject to prolonged alterations during these periods (Alderotti, Verdiani, 2023). Various abiotic factors (climate, soil, etc.) or biotic factors (insects, fungi, etc.) can combine and accelerate the process, sometimes leading to the death of the tree (Atemasov et al., 2011; Bendixsen et al., 2015). The term ""decline" refers to complex phenomena. The decline of a tree is characterized by a series of interrelated factors occurring in a specific sequence, resulting in a general and progressive deterioration that ultimately leads to the death of the tree (Pijanowski et al., 2011). It is primarily manifested by a significant decrease in foliage and the mortality of numerous branches (Anderson, Gaston, 2013) In Mediterranean regions, numerous cases of forest decline and deterioration of reforested stands have been reported in recent years. In Algeria as well, there have been several periods of oak decline during the 20th century (Zerrouki et al., 2024; Merlin et al., 2015). Foresters were the first to observe the symptoms of decline in trees and the resulting mortality following the droughts of 1970 and 2003. Oaks, which represent a precious natural resource in Algeria, encompass various species such as*: Quercus suber*, *Q. canariensis*, *Q. coccifera*, and *Q. afares*. They occupy extensive areas, especially in the north and northeast, covering approximately 40% of Algerian forests. Their disappearance could have serious consequences for the environment and society in Algeria. However, Algerian forest cover has experienced significant destruction in recent years. Its estimated area of 1.3 million ha of true natural forests has been undergoing nearly exponential regression and is currently in a distressing state. Thus far, research on oaks in Algeria has been limited (Touafchia et al., 2024), despite these oak forests being the country's only forests capable of producing wood and other applications requiring high mechanical resistance (Cohen, 1969; Atemasov, Atemasova, 2023; Keren et al., 2020).

Our research focuses on evaluating the health status of oak trees cork oak (*Q. suber* L.), zeen oak (*Q. canariensis* Willd.) and afares oak (*Q. afares* Pomel.) located in the Zouagha forest, a geographical area in the northeastern part of Algeria.This evaluation relies on the assessment of a diverse range of degeneration indices. Consequently, we have conducted dendrometric analyses in conjunction with direct observationof identifiable symptomatic manifestations on branches and canopies. The conduct of our observations has led to the need for an in situ diagnosis, primarily grounded in the ARCHI methodology, which derives its essence from tree architecture. This approach dissects the morphology of the aboveground portion of trees while integrating the sequential evolution shaped by growth, deterioration indices, as well as

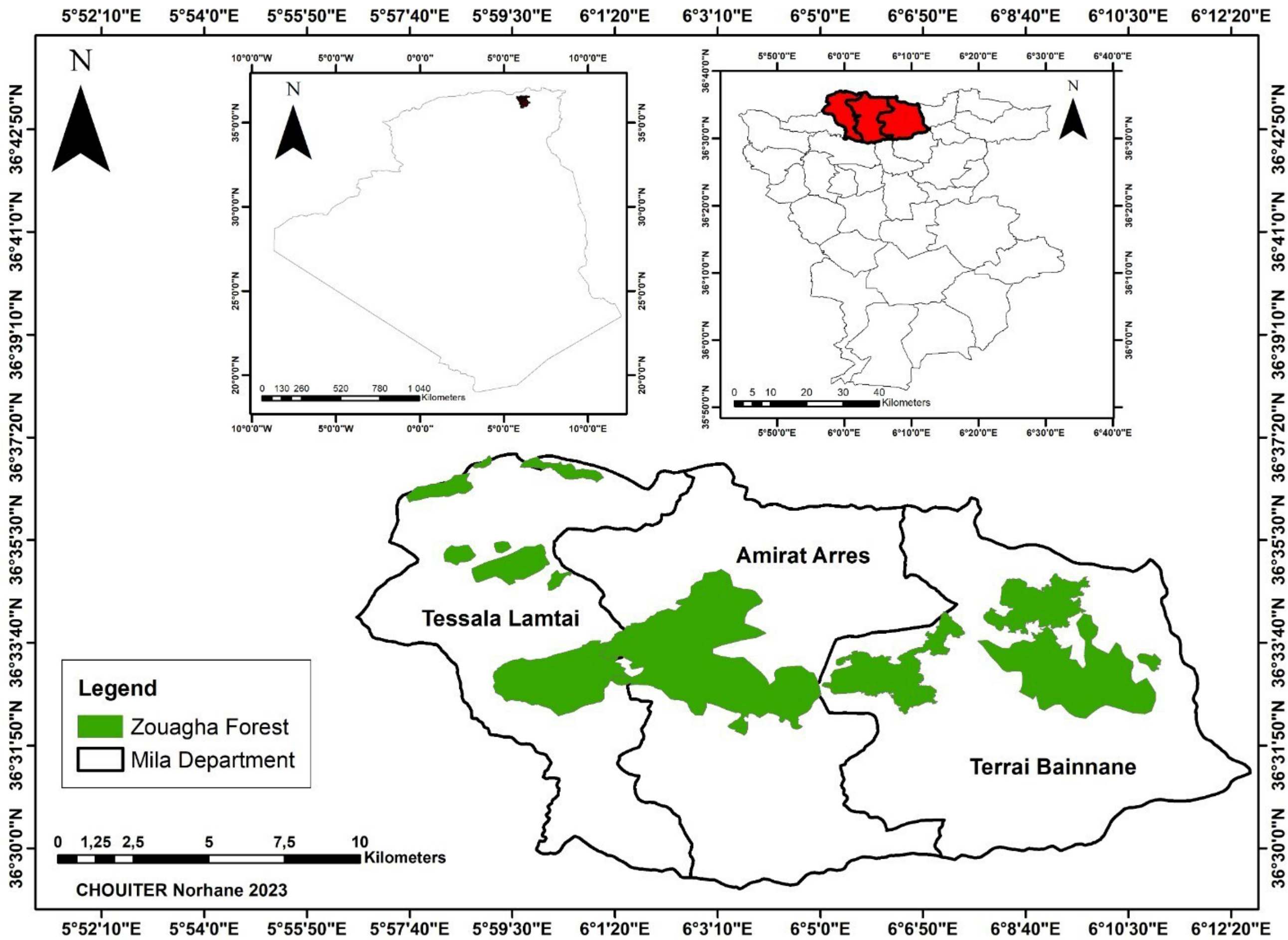

Fig. 1. Geographic location of the Zouagha forest (Chouiter et al., 2023).

the architectural configuration of the canopy (including mortality and branch impoverishment). This analytical framework also addresses canopy regeneration processes resulting from the development of epicormic branches (Drénou et al., 2011). The method for evaluating the condition of mature deciduous canopies, combining a set of elementary criteria, has thus been developed (DEPEFEU protocol). Major criteria among them include canopy clarity, branch mortality rate, and the distribution of foliar mass.

Furthermore, the quantification of biodiversity using the Potential Biodiversity Index (PBI), which serves as a tool for the taxonomic assessment of biodiversity within forest populations in a prompt and elementary manner. This strategy relies on an indirect estimation of biodiversity, based on the assessment of the capacity to host species and communities within forest ecosystems.

Material and methods

Study area presentation

The Zouagha forest is located in the northeastern region of Algeria (Fig. 1). Its coordinates range from 6°9´15.52″ E to 36°34´38.90″ N. It covers a total area of 3915 ha, and the prevailing climate in this area is subhumid, characterized by hot and dry summers and mildand humid winters. Average summer temperatures range from 25 to 30 °C, while average winter temperatures vary from 8 to 12 °C. Precipitation is relatively abundant, with an annual average of around 700 mm. Rainfall is concentrated in the autumn and winter months, with occasional heavy rainepisodes. The wettest months are November, December, and January. The Zouagha forest consists of native species, including *Juniperus phoenicea*, *J. oxycedrus*, *Pistacia atlantica*, and *Olea europaea*. Planted stands (main species) include *Quercus suber*, *Q. canariensis*, and *Q. afares*, accompanied by *Thymus vulgaris* L., *Rosmarinus officinalis*, and *Lavandula angustifolia* Mill.

Data collection

We opted for 12 study sites considering both floristic composition and altitude. The selection process followed a random sampling approach. The plots have an area equivalent to 900 m^2. Visual observations were conducted during the winter season in the year 2022–2023 (December–February). Geographic coordinates for each plot were recorded using a GPS device.

Tree Architecture Method (ARCHI)

ARCHI is a forest health assessment method developed by the National Institute for Agricultural Research (INRA) in France.

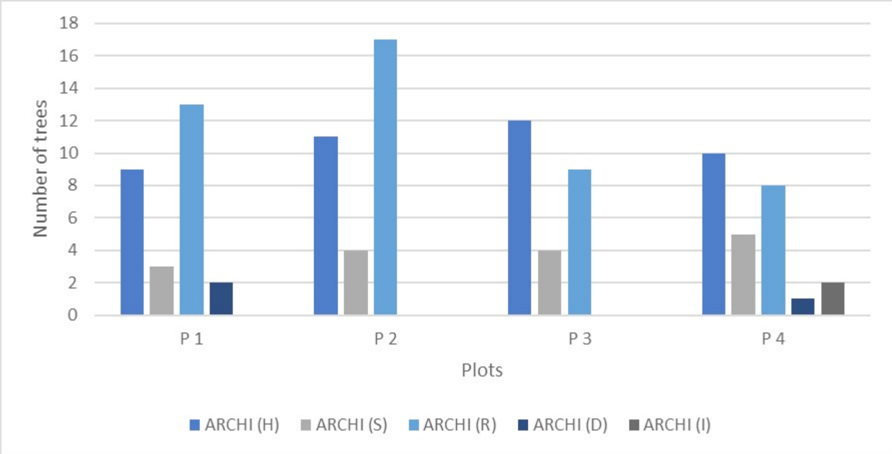

Fig. 2. Different types of ARCHI for *Quercus suber.*

It is a visual diagnostic tool developed to characterize the health status of forest stands, based on the analysis of tree architecture (Drénou et al., 2015).The principle involves conducting a series of observations: the first relates to crown degradation symptoms (a foliar deficit, abnormal coloration, mortality, etc.), and the second concerns crown restoration processes (bud development, wound healing, growth resumption, etc.).

Health Assessment Based on Crown Appearance (DEPEFEU Protocol)

DEPEFEU is an acronym that stands for "Diagnostic of Forest Phytosanitary State by Sampling." This protocol was developed in France by the National Forestry Office (Nageleisen, Goudet, 2011). DEPEFEU is used to assess the decline of hardwood forests based on a multi-criteria description of the crown. It relies on ground-level observation of symptoms that provide information about the crown's health. Three symptomatic criteria can be distinguished: crown transparency, the mortality of perennial organs (branches, twigs), and the distribution of foliarmass.

Stand Biodiversity Potential Index (PBI)

The assessment of the ordinary taxonomic biodiversity of forest stands requires the use of the Stand Biodiversity Potential Index (PBI), which is used to evaluate a set of ten factors among those generally recognized as most favorable to the internal diversity of forest stands (Nageleisen, 2005). We took into account the specific composition and structure of the stand, the supply of "microhabitats" related to trees, the presence of habitats associated with the forest, the maturityof current stands, and the continuity of the wooded state. Wetlands and open rocky environments are considered for their unique species composition and their functional role for forest stands. Each factor is assigned a score based on a threshold value scale (0, 2, and 5). The sum of the scores then assesses overall diversity with a theoretical maximum level of biodiversity (Barbeito et al., 2014). Seven factors related to stand and forest management (native species: A, vertical vegetation structure: B, standing deadwood: C, downed deadwood: D, large living wood: E, living trees providing microhabitats: F, open habitats: G, and three other factors are more context-related (temporal continuity of wooded state: H, aquatic habitats: I, and rocky habitats: J).

Results

An initial assessment of crown health is conducted using the ARCHI method, which is based on the observation and morphological analysis of the entire aerial portion.

The results obtainedfrom field surveys were limited to 4 plots for each species (*Q. suber*, *Q. canariensis*, and *Q. afares*) and are illustrated in Figs 2–4.

The oaks (*Q. suber* and *Q. canariensis*) show similar percentages across the different ARCHI classes (Figs 2 and 3), with the majority of trees classified as ARCHI R (42.72 and 40.70%, respectively) and Healthy ARCHI (38.18 and 38.05%, respectively), indicating good overall health and the presence of vigorous and numerous shoots. For *Q. afares*, the proportion of treesclassified as resilient is 45% (Fig. 4), while the proportion of stressed trees is higher (27%). These trees are more vulnerable to environmental stress and may require silvicultural interventions.

For all three species, the proportion of trees classified as D (crown descent) or I (irreversible decline), which measure the tree's vulnerability to disease and infection, is quite low (<3%), as indicated by the low presence of vigorous shoots. It is noteworthy that these trees are generally in good health and do not pose significant risks to their immediate environment. The DEPEFEU method was also used to assess the health status of oaks in the Zouagha forest;it involves evaluating the appearance of the tree crowns. The results obtained are presented in Figs 5–7.

Examining the percentages for each health status class presented in Figs 5–7, it canbe observed that the entire population of oaks in the Zouagha forest belongs to class 2 (moderatehealth status). The rates for this class are 37.27% for *Q. suber*, 32.74% for *Q. canariensis*, and 39% for *Q. afares*, indicating a health issue with the trees but not yet severely affected. Class 3(moderate to poor health status) is also quite represented for all three oaks (30.90% for *Q. suber,* 37.16% for *Q. canariensis*, and 34% for

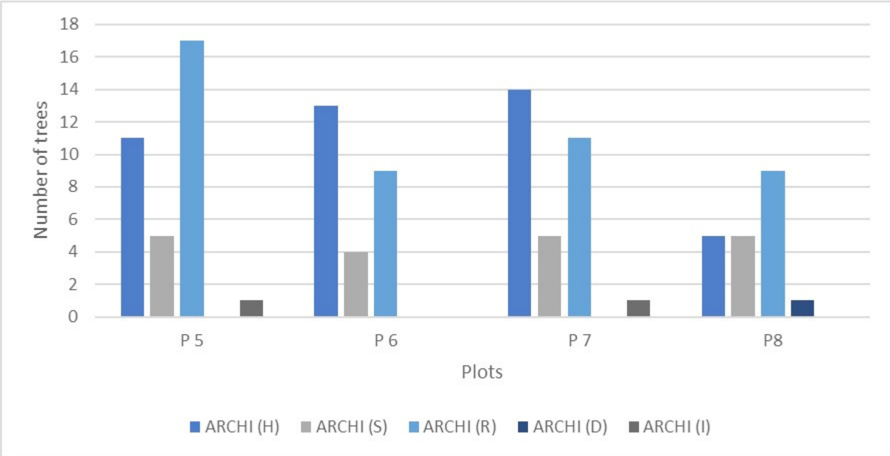

Fig. 3. Different types of ARCHI for *Quercus canariensis.*

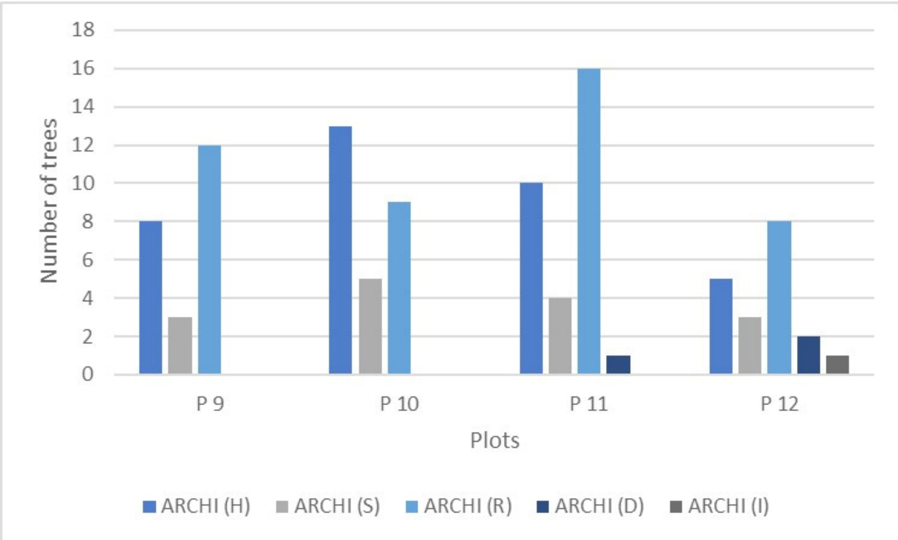

Fig. 4. Different types of ARCHI for *Quercus afares*.

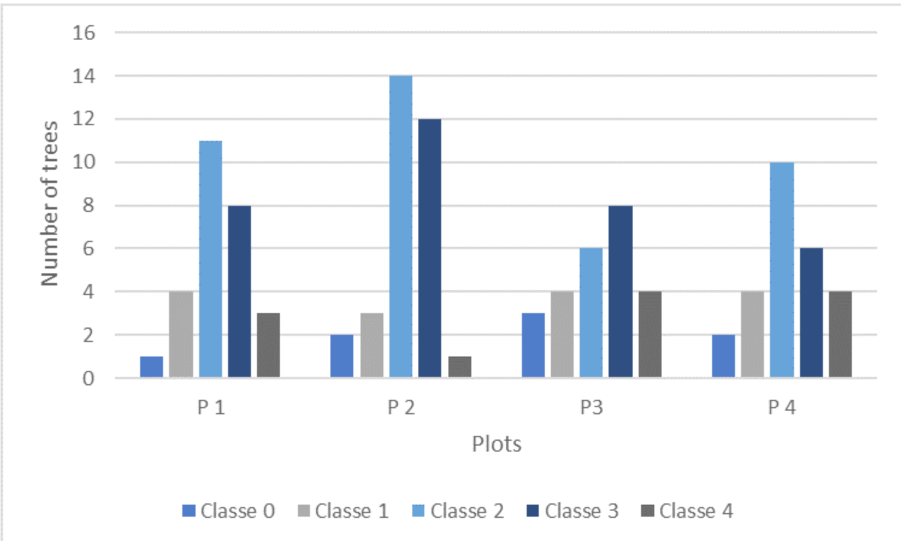

Fig. 5. Different DEPEFEU classes of *Quercus suber*.

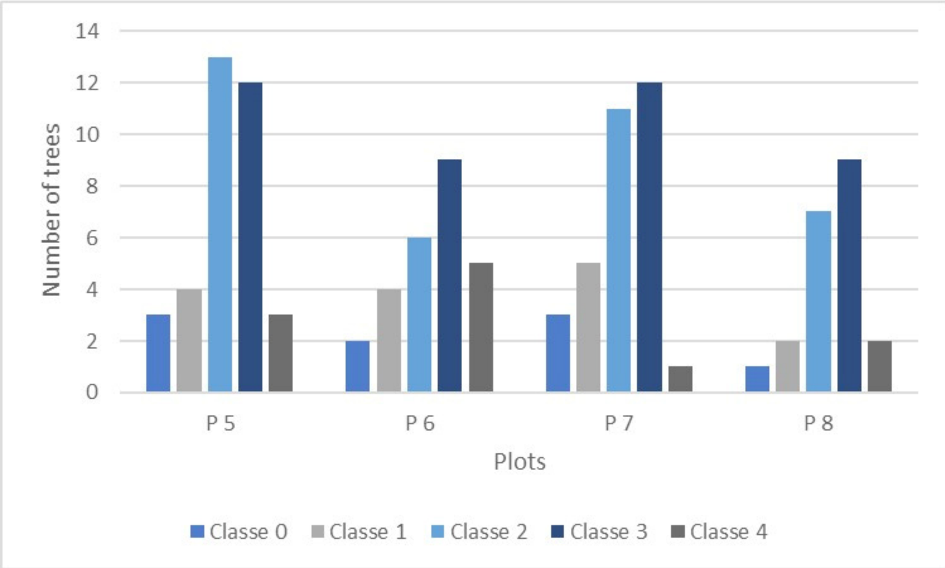

Fig. 6. Different DEPEFEU classes of *Quercus canariensis*.

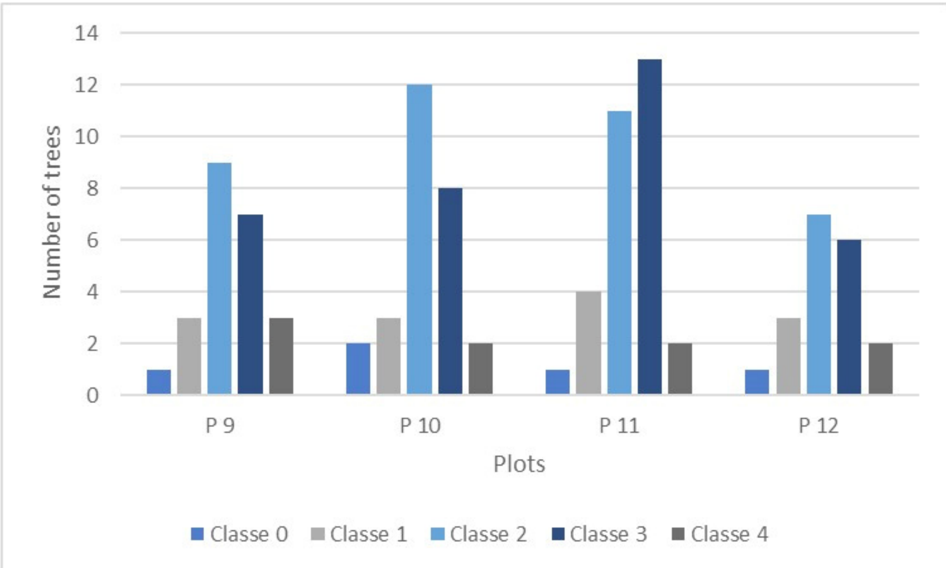

Fig. 7. Different DEPEFEU classes of *Quercus afares.*

Q. afares); trees in this class are experiencing some health problems that need to be addressed to prevent further deterioration. The proportions of class 1 (good health status) are relatively low for all oaks, hovering around 13%; these trees have health issues. Classes 4 (very poor health status) and 0 (perfect health status) are the least represented for all oaks, with high percentages of 10.90 and 7.27%, respectively, for *Q. suber;* these trees are relatively resistant to diseases and unfavorable environmental conditions where trees do not show signs of degradation. In summary, it can be concluded that the health status of this forest ecosystem for the three evaluated oaks is relatively moderate, with a majority of trees falling into classes 2 and 3, accounting for 53.01% of sampled trees. However, the presence of trees in classes 1 and 4 suggests that there are individuals experiencing deterioration or decline, requiring special attention for their management and conservation.

The assessment of biodiversity relies on employing the PBI. This index serves as a swift and user-friendly tool empowering forest manager to: (i) gauge the potential taxonomic diversity within populations (Varo-Martínez, Navaro, 2021; Rached-Kanouni et al., 2020a); (ii) identify areas for improvement through effective management practices. By integrating various factors such as specific population compositions, vegetation structures, and the presence of specialized habitats, the PBI offers a comprehensive evaluation of forest biodiversity. We will examine various factors related to population and forest management (A–G) and contextual factors (H–J). The results of the PBI obtained for the oaks in the Zouagha forest are presented in Tables 1 and 2.

Table 1. Biodiversity potential related to oak management (1st value).

Plots	Species	Absolutevalue	Relative value (%)	Potential biodiversity related to management
P1	*Quercus suber*	23	66	Fairly important
P2		20	57	Medium
P3		19	54	Medium
P4		23	66	Fairly important
P5	*Quercus canariensis*	26	74	Fairly important
P6		20	57	Medium
P7		23	66	Fairly important
P8		20	57	Medium
P9	*Quercus afares*	23	66	Fairly important
P10		20	57	Medium
P11		23	66	Fairly important
P12		18	51	Medium

Table 2. Biodiversity potential related to oak context (2nd value).

Plots	Species	Absolutevalue	Relative value (%)	Potential biodiversity related to management
P1	*Quercus suber*	12	80	Fairly important
P2		12	80	Fairly important
P3		9	60	Medium
P4		12	80	Fairly important
P5	*Quercus canariensis*	9	60	Medium
P6		9	60	Medium
P7		9	60	Medium
P8		12	80	Fairly important
P9	*Quercus afares*	9	60	Medium
P10		9	60	Medium
P11		9	60	Medium
P12		12	80	Fairly important

The factors associated with oak stands and forest management for the three oak species (*Q. suber, Q. canariensis*, and *Q. afares*) in the mentioned plots were assessed. These assessments cover various aspects such as the characteristics of forest species, vertical vegetation structure,the presence of standing deadwood, the size of living trees, the presence of microhabitats, and open environments. Regarding indigenous forest species, a score of 2 was assigned, indicatingthat the oaks are indigenous. This suggests a natural vegetation composition that is well-suitedto the region. Concerning vertical vegetation structure, a score of 5 was assigned to plots 5 and7 for *Q. canariensis* and plots 9 and 12 for *Q. afares*, indicating the presence of four strata within these plots. Conversely, we assigned a score of 2 to the other plots, which exhibited a relatively even distribution of vegetation strata. The presence of standing deadwood of substantial circumference is common in all plots, with scores generally ranging from 2 to 5. This suggests some diversity of habitats for saproxylic fauna (Coleoptera, Diptera, and Hymenoptera). Large-circumference deadwood on the ground is limited in most plots (a scoreranging from 0 to 2), potentially indicating previous management practices or natural decomposition cycles.

The sizes of living trees in the Zouagha forest generally receive high scores (5), indicating thepresence of very large living trees, which can be beneficial for biodiversity and ecological stability. Furthermore, most living trees bear microhabitats (score 5), an essential feature for preserving biological diversity (Rached-Kanouni et al., 2020b).

The presence of microhabitats is a positive sign for biodiversity and ecosystem health, as it provides ecological niches for various organisms. Open environments are common throughout most of the forest (scores ranging from 2 to 5), which is important for species diversity. Open environments create transitions between different habitats, thus promoting a variety of organisms. This observation may indicate habitat diversity within each forest stand. In summary, the context-related factors assessed by the PBI reflect a positive trend for biodiversitypreservation and forest ecosystem health. Microhabitats and open environments are present in the evaluated plots for all three oak species, enriching biodiversity and supporting various organism groups (Lebourgeois et al., 2019).

The context-related factors assessed by the PBI for the three oak species (*Q. suber, Q. canariensis*, and *Q. afares*) in the

Zouagha forest focused on the temporal continuity of wooded areas, aquatic habitats, and rocky environments. For all these oak species, the plots exhibit a high level of temporal continuity of wooded areas (score 5). This indicates that the forest standsare relatively stable and have retained their wooded character over an extended period, promoting the stability of the forest ecosystem and the preservation of its natural characteristics.Regarding aquatic habitats, scores vary between plots and species, with scores of 2 and 5 observed. These variations can be attributed to the site's topography and the presence of water.For rockyenvironments, assigned scores are generally 2 for the oaks in this forest. The presenceof rocky environments can provide specific habitats for certain species, thus contributing to thediversity of the forest ecosystem. Aquatic and rockyenvironments contribute to habitat varietyand create ecological niches for different species.

Total scores for the oak stands in the Zouagha forest range from 28 to 35, with a percentage 56–70% of maximum potential. According to the PBI scale, they are classified as moderatelyhigh. This potential (1st value) is assessed in absolute values and relative to a theoretical maximum. The absolute values for all three oaks are comparable, ranging from 9 to 12 for biodiversitypotential related to the context (2nd value). Relative values vary from60 to 80%of the theoretical maximum. In terms of context, degrees of importance are mostly moderate interms ofcontribution to biodiversity. In summary, the results show that in terms of management,context, and overall PBI, the three oaks have slightly varying levels of biodiversity potential. *Q. suber* and *Q. canariensis* are often considered to have relatively high potential relevance compared to *Q. afares.*

Discussion

In our study, the results obtained reveal that the majority of trees are of type ARCHI R (42.82%). Trees of this type exhibit specific characteristics: in the absence of additional stress, they can recover to a healthy state. Regarding the width of growth rings, after a period of decline, radial growth re-establishes itself. Thus, a resilient oak has favorable potential for development (Müller et al., 2020). Stressed trees or ARCHI S represent 19.45%. In this case, it is challenging to make predictions about their future because it is believed that the stress is recent (Kasten et al., 2012; Froidevaux et al., 2014; Depraetere et al., 2012). Sometimes, successive stresses on oaks manifest on already present shoots.

However, these results are similar to those obtained in a study conducted in the Machrouha forest in Souk Ahras by (Lyazid et al., 2021). In any case, it is necessary to monitor the evolution of ARCHI S-type trees over time before making a prognosis.

For healthy trees, the significance of water deficit is less, but it appears that its role has considerably increased in recent years, influencing the formation of the growth ring, which has also become dependent on the water balance. This change in tree response over time has been observed in many European contexts and is often interpreted as a standardization of ecosystem responses to increased constraints (Camarero et al., 2015; Toïgo et al., 2020; Emberger et al., 2013). Knowledge of the architecture of trees from various species has allowed forestry professionals to apply these concepts and establish observation protocols for architectural diagnosis, providing insights into the level of stress experienced by the tree, its reactivity, and thus enabling predictions of its development (Bateman, Uzal, 2021). The observation is similar to that reported by Miłosz (2022), who highlighted concerns about the situation of oaks throughout the Mediterranean region, especially in the Maures and Esterel in France. Indeed, the decline of oak forests in the western Mediterranean region since the 1980s (Connell, 1978) has been partly attributed to a significant increase in population of *Platypus cylindrus*. This formidable pest and the fungi it carries have been implicated in concerning declines reported in Portugal (De la Cruz et al., 2014), Spain, France, and Morocco (Costanza et al., 2014). Other biotic and abiotic factors can also influence forest health. Essential information to understand changes in forest structure includes tree age, size, and deterioration history (Lee et al., 2014). Short-term stress factors such as defoliation caused by insects or extreme climatic variations can lead to tree decline, but when these stress factors are removed, trees generally recover and are sometimes highly resilient (Bouget et al., 2023, Bukachenko, Naglov, 1954). This is exactly the case in the Zouagha forest, which experienced a level 1 defoliation according to the mapping of data sheets for the *Lymatria dispar* population in 2022. The health of a tree or forest stand is not solely defined by the presence or absence of aggressors (insects, fungi) or the manifestations of their activities (symptoms) but also by a correct growth state dependent on edaphic and climatic constraints, as well as competition with other trees. Several studies have been conducted to explain the phenomenon of forest stand decline, such as those carried out by Ostry et al. (2011) and Trouvé et al. (2015). These studies classified the responsible factors into three categories: predisposing, triggering, and aggravating factors, the relative importance of which varies by region. Therefore, it is challenging to satisfactorily explain the exact origin of this decline, as assessments of the causes of decline can vary from one author to another (Nguyen et al., 2016; Castello et al., 2016; Encinas-Valero et al., 2022).

The PBI is a diagnostic tool designed to guide management decisions at the level of forest stands. It is user-friendly enough to encourage its use during diagnostics conducted by forestryadvisors (Pausas, Keeley, 2017). The results show that the potential forest biodiversity of the Zouagha forest is moderate. The values obtained for the criteria in this forest often depend on climate, soil, and anthropogenic actions. However, these results are similar to those obtained in a study on the potential biodiversity assessment of forest stands in France by Yvonne (2012). According to the PBI scoring scale, the values obtained are moderate for the first score and quite significant for the second score. This result can assist forestry managers in improving the functioning of the ecosystem and the taxonomic biodiversity of forest stands. A high score can be achieved through appropriate management. However, although it incorporates many elements, the PBI can be integrated into a sustainable forest management approach. It is essential to remember that this approach is not limited to biodiversity and requires the assessment of other factors, including forest health and vitality, as well as the suitability of tree species for local conditions. The use of the PBI does not preclude the possibility of more in-depth studies on biodiversity when the situation requires it, but it allows for the consideration of biodiversity in many forests stands where a comprehensive analysis may not be feasible. Furthermore,the PBI has educational value that contributes to making the concept of biodiversity more accessible to a wide audience, thus promoting better integration of biodiversity considerationsinto everyday management.

Conclusion

Forests in Algeria are facing a concerning situation of decline. This phenomenon results from the progressive deterioration of trees, caused by various biotic and abiotic factors, and their interactions. Our work focused on a study of the health status of oak forests (*Quercus suber*, *Q. canariensis*, and *Q. afares*), as well as an estimation of biodiversity potential based on field observations using the ARCHI, DEPEFEU, and IBP methods conducted on individuals of eachspecies. The results of the health assessment of oaks in the Zouagha forest reveal that the majority of trees are in a moderate health state. *Q. suber* and *Q. canariensis* show good overallhealth and an ability to recover from diseases and environmental stress. In contrast, *Q. afares* appears more vulnerable to environmental stress and may require additional care. Silviculturalinterventions and strategies for land and vegetation management are necessary to ensure the viability of this ecosystem by promoting species regeneration and establishing a permanent ecological monitoring system. These strategies are especially important in the context of potential global climate change, which could lead to rising temperatures and reduced precipitation. It is also essential to develop research programs to study the forest decline in Algeria, aiding managers in adopting appropriate solutions for conservation and sustainable forest resource management.

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