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OPTIMIZATION OF OAK FOREST MANAGEMENT PRACTICES IN SOUTHERN GREECE

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Abstract

The oak forests in Mediterranean are widespread and dynamic natural ecosystems. For millennia, oak forests have provided vital ecosystem services to humans in the Mediterranean including social, economic and environmental services and goods; however, in parallel, human exploitation has altered their structure. Consequently, targeted management approaches are required to optimize the production. In the current study we analyzed the structural characteristics of the Foloi oak forest (*Quercus frainetto*) in the wider area of Ancient Olympia, Peloponnese, Greece. An extensive fieldwork was applied in 29 randomly located plots in order to collect dendrometric characteristics of 938 individual trees. The collected data were used to build models for estimating tree age, tree height and canopy length from diameter at breast height (DBH). All models were found to have an adequate fit and provide useful tool for the assessment of site structural and growth characteristics. Furthermore, we present a model for assessing site quality from topographic characteristics such as slope and exposition. Finally, we employed a stand visualization tool to get a graphical representation of the stand structure, which can be used in order to adopt appropriate silvicultural practices. We believe our findings will provide useful tools to forest managers and practitioners for the sustainable management and restoration of oak forests.

Key words: *Quercus* sp., silviculture, stand structural analysis, stand visualization system (SVS).

Introduction

Deciduous oaks form extensive forest ecosystems across Europe and they are associated with high ecological, cultural and socio-economic importance (Eaton et al. 2016). In Greece oak forests cover 1,471,839 ha representing 22.6 % of the country›s forested area (Hellenic Ministry of Agriculture 1992). Hungarian oak (*Quercus frainetto* Ten.), a subendemic south European species (Stupar 2020), is the most common oak species in Greece, forming both pure and mixed stands *Q.*

petraea (Matt.) Liebl. and *Q. pubescens* Willd. are also common species, with the former forming pure and mixed stands and the latter most commonly found in mixed stands with other thremophilous deciduous oaks (Konstantinidis et al. 2002, Bergmeier and Dimopoulos 2008). Oak forests are characterised by low standing timber volume, largely due to the traditional coppice management, with short rotation cycles, which do not allow the growth of large timber volumes (Chatzifilippidis and Spyroglou 2006). Because deciduous oaks mainly grow at relatively low altitudes, rarely exceeding 700–800 m a.s.l., they are easily accessible, which results in constant interactions with humans. Consequently, intensive human pressure impacts their structure and composition, as well as the soil, potentially degrading the ecosystem as a whole.

Grazing, when it occurs in high intensities, is a common degradation factor in many oak forests, with several negative impacts on their structure, composition and regeneration capacity (Kyriazopoulos et al. 2010, Papachristou and Platis 2011, Milios et al. 2020). Another common degradation factor in those forests is the extensive and often illegal cutting of firewood by the local inhabitants, which leads often to the restriction of well-structured oak forests only to the less approachable areas (Milios et al. 2014). However, the most important degradation factor of oak forests in Greece and elsewhere, including the *Q. frainetto* forests, is the traditional coppice management with rotation cycles rarely exceeding 35 years. This practice, apart from the low productivity, results in poor stem quality, low stem densities and high rates of erosion, due to the relatively low soil coverage (Chatzifilippidis and Spyroglou 2006).

The degradation of oak forests can be mitigated by elucidating the degradation causes and understanding the ecosystem's functioning and dynamics over time. Appropriate management interventions that facilitate their multifunctional role and achieve sustainable use of forest resources can ensure social acceptance, economic benefits, and efficient environmental protection (Carella 2015). Restoring the structure of oak forests through sustainable management is challenging, but at the same time necessary in order to address the contemporary requirements for biodiversity conservation and environmental protection and at the same time, maximization of economic and employment benefits (Chatzifilippidis and Spyroglou 2004).

A particularly important prerequisite for sustainable management of oak forests is the accurate determination and mapping of site quality and forest structure, which constitute the foundation of proper silvicultural practices (Spyroglou 2004). Site quality is gauged by the amount of wood that a forest can produce. It incorporates the effects of light, humidity, fertility, and general soil properties of forests, as well as the level of photosynthesis (Davis et al. 2001). Thus, site quality can be defined as the ability of a given forest species or forest type to produce wood in a given area (Clutter et al. 1983). In practice, in order to assess site quality, a characteristic must be selected that can be easily and accurately measured, and is relatively independent of stand density and, if possible, relatively independent of the forest species (Spurr 1952). Because site quality is the sum of many interacting factors, the process of finding a simple indicator is extremely complex, and sometimes impossible. Of all the parameters that have been investigated, correlating site quality with tree height represents a long-standing and reliable approach (Davis et al. 2001). The numerical site quality index, which is defined as total tree height at a fixed age, base age, or reference age, is also employed for assessing site quality. Base and reference age are usually close to the mean age of the forest rotation time. However, in practice the age selected as the reference age is of minor importance for the determination of site quality since it is loosely correlated to tree height, after a certain age threshold (Clutter et al. 1983).

In the current study, we investigated the potential of improving forest management through implementing appropriate analysis and modelling approaches in the Foloi oak forest in southeastern Greece. This was achieved by conducting a detailed evaluation of forest structure, site quality, and dendrometric parameters. The key objectives were to: a) develop a tree age prediction model, b) define and map site quality, and c) statistically evaluate forest structure using simulations in the Stand Visualization System (SVS) program. These analytical tools are expected to provide the opportunity for the forest managers to make rational decisions regarding the sustainable management of this oak forest region.

Materials and Methods

Study area

The Foloi oak forest is situated in Ancient Olympia on the western part of the Peloponnese peninsula in southwestern Greece. This forest region has high ecological, environmental, historical, and mythological value. The ecological and environmental quality of the forest is reinforced by it being an important region for birds of Greece, based on Habitats Directive (92/43/EEC) of the Council of the European Union, for the conservation of natural habitats of wildlife and native flora. This region is also a Natura 2000 Site of Community Importance (SCI; GR2330002) named ‘Oropedio Folois’ (European Commission 2020). The mythological value of the oak forest is widespread, with its namesake being that of the good and hospitable centaur ‘Folos’, son of ‘Silinos’ and the nymph ‘Melia’, and friend of ‘Hercules’. Centaurs formed a major component of ancient Greek Mythology, with the body of a horse and chest, arms, neck, and head of a man. The Foloi oak forest covers 18,625 ha at an average altitude of 688 m. The area encompasses dense stands of deciduous oak trees (21.9 % of the area), in addition to conifers 6.2 %, evergreen broadleaves (27.6 %), cultivated areas (27.8 %), and open and rocky areas (16.5 %) (Fig. 1). The climate of the study area is Thermo-Mediterranean with mild winters and dry summers and a period of physiological draught lasting for four months between June and September. The forest is managed since 1969 by the local forest office with selective logging and a revisiting time of 10 years. However, since 2000 no logging activities occurred in the oak forests of the area in an attempt to recover the standing volume, which had been reduced due to the coppicing-based management and the relatively short rotation time.

Data collection

Twenty-nine sampling sites of 0.1 ha each (50×20 m), were randomly located using the Sampling Design Tool extension in the ArcGIS 10.7 platform and precisely placed in the field (Fig. 2). The plots were fenced for protection from grazing and other disturbances and all trees with a di-

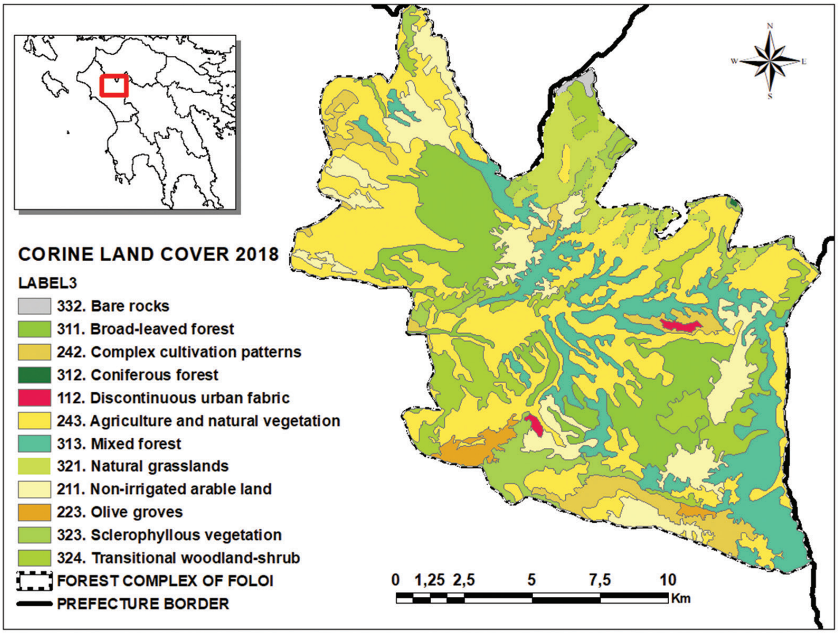

Fig. 1. Study area and land cover of the Foloi Forest Complex, Ancient Olympia, Peloponnese, Greece.

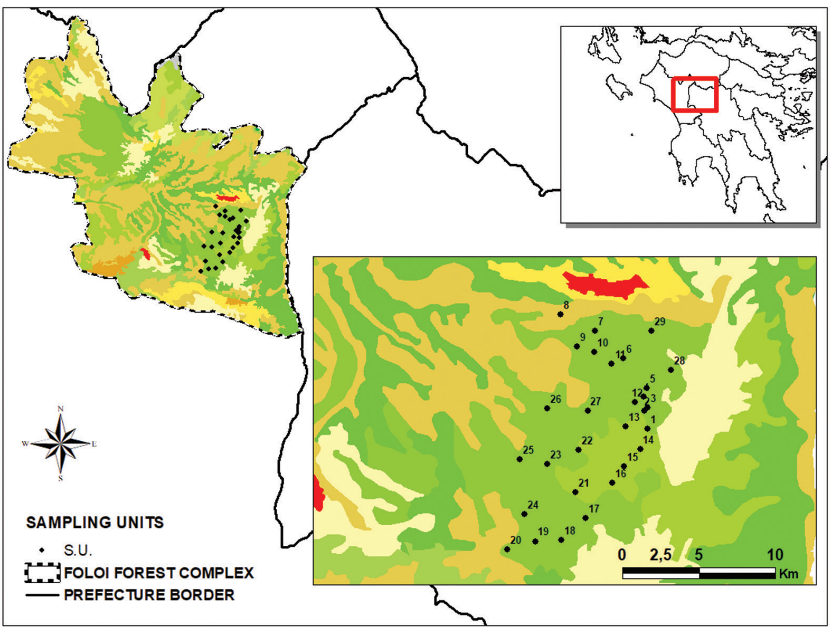

Fig. 2. Distribution of the sampling sites in Foloi Forest Complex, Ancient Olympia, Peloponnese, Greece.

ameter greater than 4 cm were numbered. For these trees, the Diameter at Breast Height (DBH), height, and Canopy Base Height (CBH) were measured, along with the width of the canopy. The CBH was determined as the height until the first live branch. The vertical position of the crown, the vitality, and the dynamic of each tree was evaluated on the field based on the vertical position and the competition parameters of the stand.

Calipers and diameter measurement tapes were used to estimate the diameter at breast height (DBH) of trees. A Pressler Increment Borer was used to determine age and increment rate. A Vertex Laser Geo hypsometer, an MDL LaserAce 300 distance meter, and a compass were used to determine tree height and the polar coordinates. GPS receivers were used to determine the geographic coordinates. Esri ArcGIS software (GIS) and R-based statistical data processing packages (libraries) were used for the analyses. The statistical correlation of dendrometric and incremental data are shown in Table 1.

Table 1. Overall statistical correlation of dendrometric and incremental cores.

Indicator	N	DBH	H	BA	CBH	CL	V
N	938	-0.841	-0.577	0.027	0.352	0.123	-0.317
DBH		1	0.767	0.252	0.352	0.047	0.604
H			1	0.453	0.788	-0.033	0.875
BA				1	0.600	0.794	0.675
CBH					1	-0.010	0.792
CL						1	0.242
V							1

Note: N – Total number of trees measured, DBH – diameter at breast height, H – height, BA – basal area, CBH – Canopy Base Height, CL – average length of canopy, and V – wood stock.

To formulate the age prediction model, 50 points were randomly selected on a georeferenced map, in order to cover all present diameter classes, and they were located on the ground using a GPS. Using these points, and with a random number of azimuths (0 to 360 degrees), the nearest tree with a diameter greater than 10 cm was selected. A corresponding core was obtained with the Pressler incremental borer to determine age. Furthermore, for the determination of age, 12 tall trees were logged, and their age was recorded at the breast height. Using the DBH as explanatory variable and the age as a dependent variable, multiple models (e.g. linear regression, Poisson, binomial negative, gam) were tested to find the one with the best fit. The lowest Akaike Information Criterion (AIC) value and the R^2 adjusted were used as criteria for fit. The packages vcd, ggplot2, car and calibrate were used in the programming language R (R Core Team 2016).

Site quality of each plot was initially determined using three different methods. The first one is based on an empirical approach (site succession), which assumes that site quality is affected by the position of a site on the slope, the aspect of the site and the average slope. According to this approach, sites at the bottom of the slope have the highest quality, those in the middle of the slope are of intermediate quality and sites at the top of the slope, on south and west aspects, and on sharp slopes have the worst site quality. The second method used to determine site quality was based on the model described by (Apatsidis 1995) for oaks, which calculates a site quality index (SQI) based on the highest stand (plot) height according to the equation (1).

$$SQI90 = \frac{H_o}{1.2380145}[\exp(-\frac{19.2158}{A})] \text{ , (1)}$$

where: $SQI90$ is the site quality index at a predetermined age of 90 years; H_o is the highest plot height in m; and A is plot age at DBH in years.

The third method which was used for the determination of site quality is similar to the previous one with the only difference being that in equation (1) the highest plot height is replaced with the average plot height. Once the site quality was determined using the three methods described above, multiple regression models were built in order to model the relationship between topographic characteristics (i.e. altitude, slope, aspect) and site quality. The Site quality, as determined by the three methods above, was used as dependent variable in the models and the topographic characteristics as the independent variables. The final products of this modelling approach are maps showing the distribution of site quality classes across the area.

An important parameter of sustainable forests management is the ability of the forest manager to estimate important dendrometric characteristics, such as height and crown length, using simple measurements such as the DBH. For this reason, various models were tested to develop allometric equations between height and DBH (height-diameter model) and Crown Length and DBH (crown – diameter model). For the height-diameter model, five basic non-linear models were tested (Table 2), which were adjusted for the total sample size. The general format of the models is shown in equation (2). A fixed term of 1.3 was used to avoid predicting individuals with a height less than the breast height when diameter approaches zero. For the crown-diameter model, linear and power models (Table 3) were tested. The goodness of fit of all tested models was evaluated based on the Coefficient of Determination (R^2), the Akaike Information Criterion (AIC) and the Root Mean Squared Error (RMSE) (Huanget al. 1992, Sharma 2009):

$$h_i = f(D_i, b) + \varepsilon_i, \quad (2)$$

where: h_i is tree height (m) of i^{th} observation, D_i is DBH (cm) of the i^{th} observation, b is the vector of the parameters, ε_i is the unexplained part – remaining – which are random and follow the normal distribution.

The forest structure was further simulated using the Stand Visualization System (SVS) program (McGaughey 1997). SVS is a program that allows the automatic design of geometric (vector) representations of forest stand structure (usually a sample plot) primarily using detailed dendrometric data at individual tree level. Descriptive parameters in the model included field measurements that corresponded to the surfaces of 50×20 m (0.1 ha) dimensions. The existing structure of each stand was evaluated using the distribution of diameter classes, degree of soil cover, distribution of height classes, trunk/crown ratio, and the species composition of stands, including subcanopy species.

Results and Discussion

Based on these 62 measurements of age trees (50 trees from increment core and 12 trees from sample disks), average diameter was 32.24 cm (range: 13–57.4 cm;

Fig. 3). Mean measured age was 103.34 years (range: 26–170 years).

Among the models tested to determine tree age based on DBH the linear regression model was found to have a good fit to the data ($F_{1.60}$ = 146.5, p< 0.001, R^2 adjusted = 0.7045; Fig. 4), which resulted to the model shown in equation 3 and the result was also used as input data in equation (1). The rest of the tested models (Poisson, binomial negative, gam) resulted in an R^2 adjusted not exceeding 0.62).

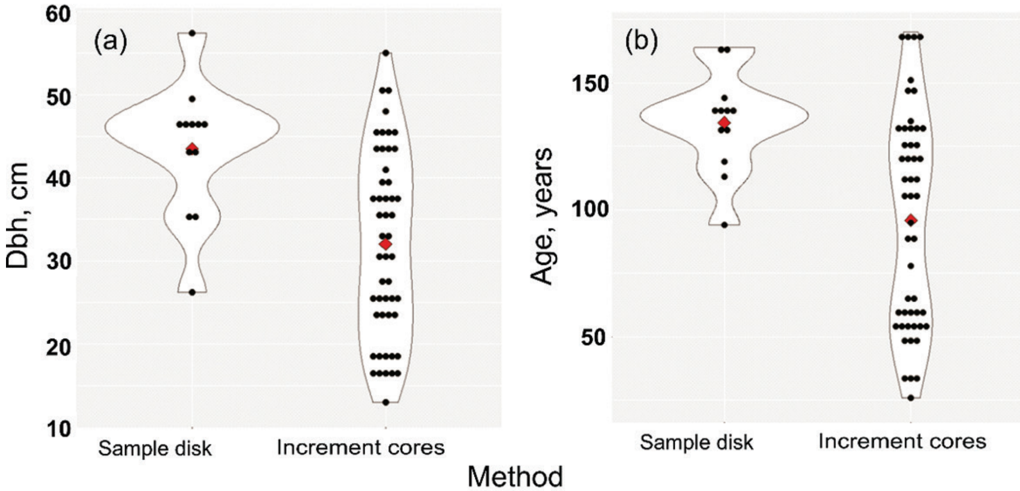

Fig. 3. Violin plots showing the distribution of DBH (a) and age (b) according to sample disk and increment core.

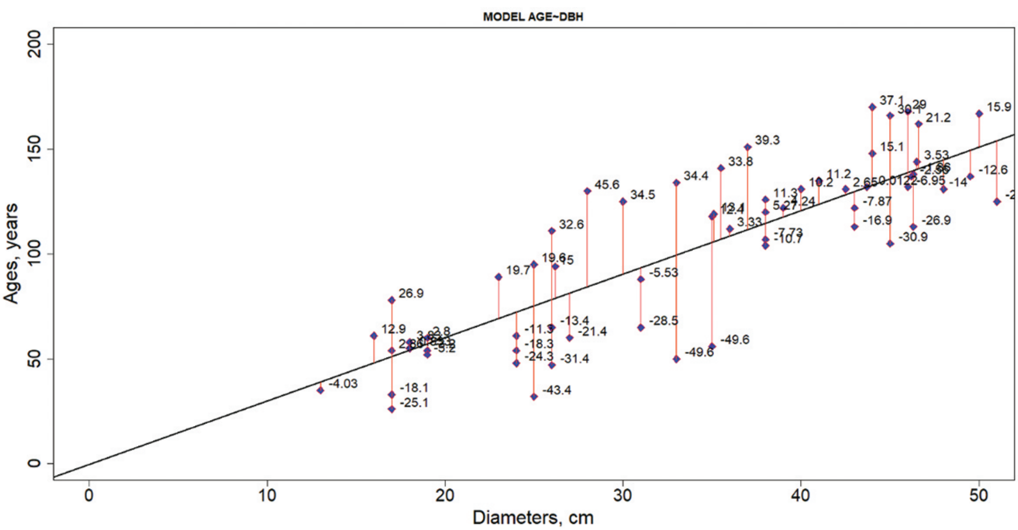

Fig. 4. Relationship between age and DBH based on the General Linear Model, showing predicted values and residuals.

$$A = -0.3373 + D \cdot 3.0280, \quad (3)$$

where: A is age, in years; D is diameter of DBH, in cm.

Regarding the determination of site quality, substantial differences were observed across the three models, which were built based on the three methods for estimating Site quality. The three multiple regression models associating site quality with topographic characteristics are shown in equations (4), (5) and (6) for the estimation of Site Quality (SQ) based on the empirical approach, the equation by Apatsidis (1995) using the highest plot height and the average plot height, respectively.

$$SQ = 3.838 - 0.002 \cdot A + 0.005 \cdot S - 0.903 \cdot N - 0.344 \cdot E, \quad (4)$$

$$SQ = 8.282 - 0.009 \cdot A + 0.006 \cdot S - 0.140 \cdot N - 0.225 \cdot E, \quad (5)$$

$$SQ = 8.129 - 0.014 \cdot A + 0.050 \cdot S - 0.197 \cdot N - 0.291 \cdot E, \quad (6)$$

where: A is altitude, in m; S is slope, in º; N is northness, in º; E is eastness, in º.

The three equations above were employed to map the site quality across the entire area. Based on the researcher's experience of forest conditions and topographical oak forest characteristics, the multiple linear regression model, built using the empirical approach for estimating site quality reflected the actual conditions more accurately than the other two models, while it also had the best fit ($R^2 = 0.7995$; F-statistic = 23.93; p-value < 0.001) when used as explanatory variable in the tested models. Using the developed model, 1265.514 ha (31.03 %) were classified as site quality I; 1687.624 ha (41.38 %) as site quality II; and 1125.219 ha (27.59 %) as site quality III (Fig. 5).

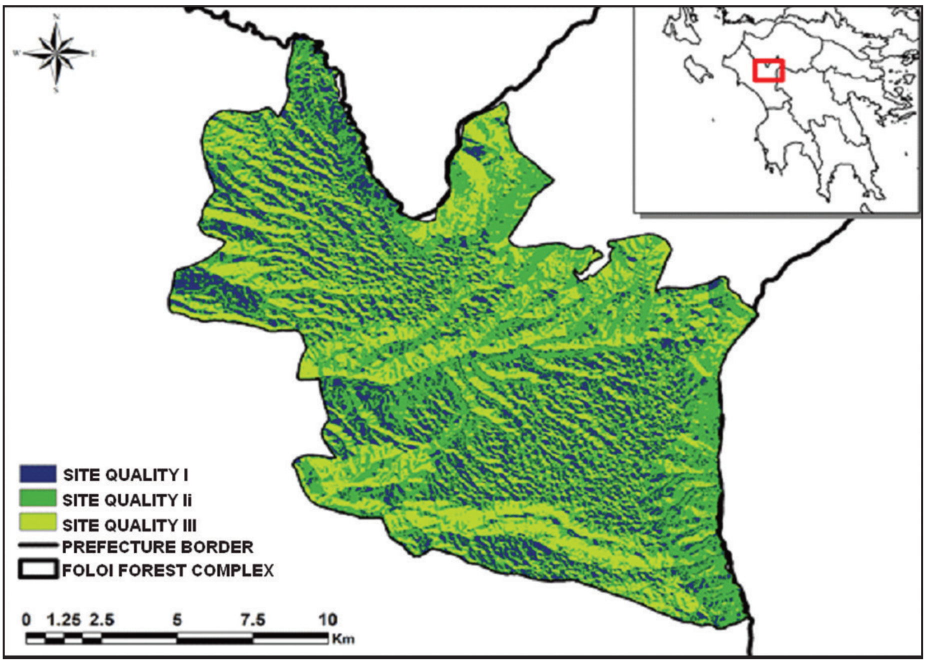

Fig. 5. Spatial distribution of site quality based on the empirical model 'site succession' in Foloi Forest Complex, Ancient Olympia, Peloponnese, Greece.

The distribution of observations regarding Height and DBH exhibited a concave curve, as a result of intense intraspecific competition in the cluster (Fig. 6a). All tested variants for the development of height-diameter model were found to have an R^2 reaching and exceeding 0.7; however, the Richards model was found to have the best fit to the data with the highest R^2 and the lowest AIC and RMSE (Table 2).

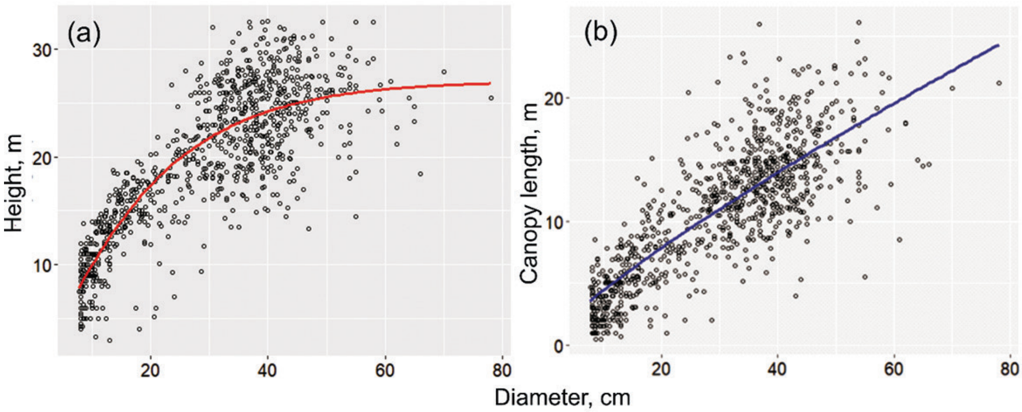

Fig. 6. Graphical representation of the adaptation of (a) the model of Richard's (1959) on height–DBH data for the entire oak sample (including sites of all qualities) and (b) the Power model on crown–DBH data for the entire oak sample (including sites of all qualities).

Table 2. Mathematical expression of the height to DBH models tested, estimated parameters, and good fit criteria.

Model	Reference	*a*	*b*	*c*	R^2	RMSE	AIC
$h = 1.3 + \frac{D^2}{(aD+b)^2}$	Näslund (1936)	0.16	1.66	-	0.73	3.547	5043
$h = 1.3 + a \cdot \exp(-bD)^{-1}$	Schumacher (1939)	31.54	13.08	-	0.73	3.542	5041
$H = 1.3 + aD^b$	Power	2.638	0.58	-	0.70	3.755	5150
$h = 1.3 + a[1-\exp(-bD)]^c$	Richards (1959)	25.77	0.06	1.45	0.74	3.524	5033
$h = 1.3 + a \cdot \exp(\frac{-b}{D+c})$	Ratkowsky (1983)	32.91	15.23	1.428	0.74	3.538	5040

Note: values of all parameters were statistically different from zero ($p < 0.05$).

Canopy length is an important parameter of stand structure reflecting the growing conditions, the photosynthetic ability and the competition between individuals, while it determines to a great extent the necessary silvicultural measures that need to be adopted for improving stand structure and productivity. As a result, models determining crown length from simple measurements, such as DBH, are of particular importance allowing the estimation of the growing space of individuals and stands (Nutto et al. 2006). Of the two tested models, the power one was found to have the best fit to the data with the highest R^2 and the lowest AIC and RMSE (Table 3, Fig. 6b). Although R^2 does not exceed 0.7, given the large number of factors involved in determining the crown length of individuals, it is considered adequate and can be incorporated into forest management practices and decision making.

Table 3. Mathematical expression of the crown to DBH models tested, estimated parameters, and good fit criteria.

Model	Reference	*a*	*b*	*c*	R^2	RMSE	AIC
$cl = aD^b$	Power	0.65	0.82	-	0.68	3.06	477
$cl = a + bD$	Linear	1.13	0.32	-	0.67	3.11	479

Analysis of site structure based on the SVS simulation showed that Foloi oak forest primarily had a homogeneous form with a single-layered structure. However, the current form of the majority of the oak forest in the area does not allow the provision of the full range of ecosystem services that could otherwise provide, including biodiversity related services, social services and of course, economic services. Ideally, stands should contain a mix of ages and a multilayer structure similar to the one observed on plot 17 (Fig. 7). However, this was the exception, rather than the norm in our data and most plots had a vertical structure similar to the one observed on plot 26 (Fig. 8).

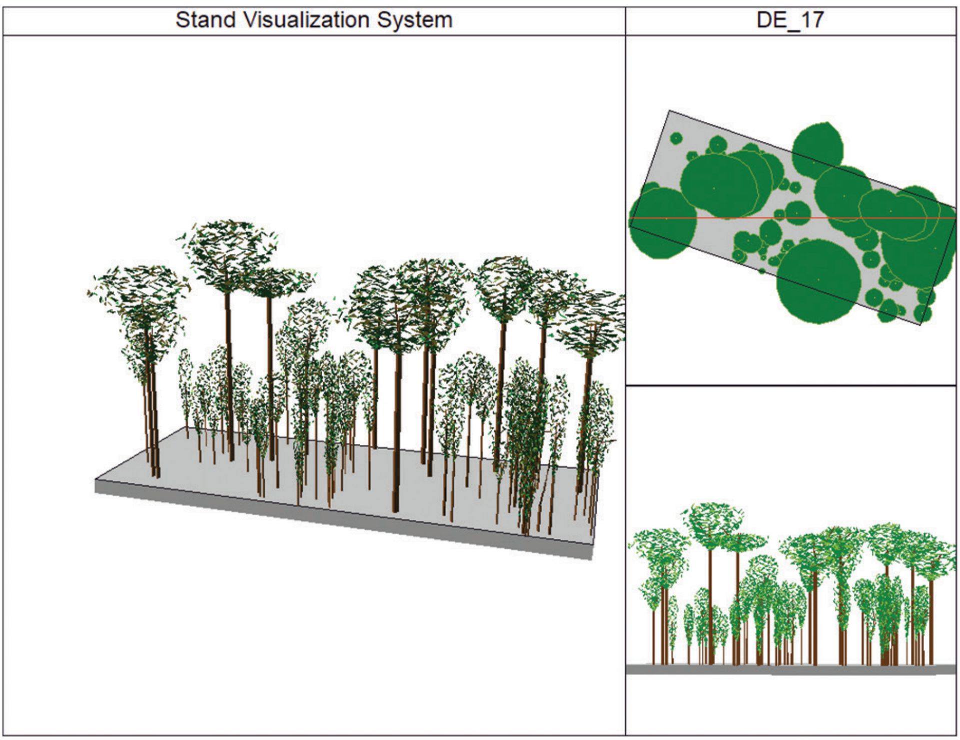

Fig. 7. Three-dimensional display of the profile (left), horizontal structure (top right), and vertical structure (bottom right) of the Sampling Site 17.

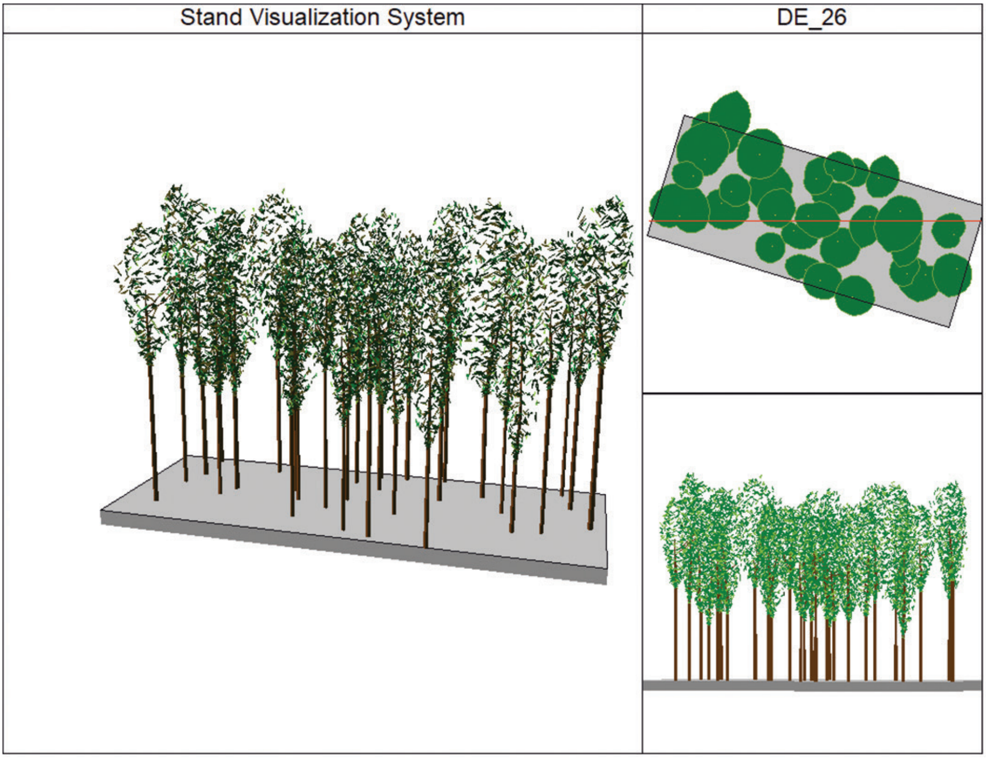

Fig. 8. Three-dimensional display of the profile (left), horizontal structure (top right), and vertical structure (bottom right) of the Sampling Site 26.

Foloi oak forest may constitute a model region for achieving a balance between forest management and conservation measures. The conditions required to enhance growth can be used as a tool to optimize appropriate forestry practices, towards enhancing the protection of the natural environment, which includes a large number of functions and services, like primary production and income generation (Chatzifilippidis 1997). Combining models with remote sensing approaches is expected to further enhance forest management at an applied level (Gering and May 1995). Such growth models simulate the evolution of stands under different management regimes, facilitating improvements in forest management design (Chatzistathis et al. 1996), with obvious implications in the corresponding silvicultural practices.

Conclusions

Many oak forests in the Mediterranean region are degraded with their sites having lost a significant part of their productivity as a result of overexploitation and mismanagement for several decades if not centuries. Forest management must be implemented with the principles of sustainable forestry to support the economy, provide suitable habitat for many species, increased ecosystem services, and contribute to the creation of sustainable and resilient natural ecosystems with sufficient adaptability to the projected climate change. Appropriate silvicultural and management measures for the restoration of structure and productivity of those ecosystems should be based on reliable measurements of the dendrometric and structural characteristics of the stands. The current study provides useful tools in this direction. We have presented mathematical models with relatively high accuracy for determining stand age, height and crown length from simple measurements such as DBH. Furthermore, we presented a model for the estimation of site quality based on topographic characteristics, which can be easily estimated using freely available data such as Digital Elevation Models (DTM). Although, one has to be careful when extrapolating models build for a particular site, we believe that the adopted approach is not site-specific and with relevant adjustments can be extrapolated to other areas of similar climatic, topographical and vegetation characteristics. Finally, the stand simulation using SVS is an extremely useful tool for the visual representation of stand structure, which can direct forest managers towards the appropriate silvicultural practices to ensure long-term sustainability of oak forest in the Southern Mediterranean. In our view the forest structure should shift to include trees of mixed ages to correspond better to the typical model of natural forests.

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