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Alternative sampling methods to estimate structure and reproductive characteristics of Aleppo pine forest in Tunisia

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Abstract

Aleppo pine had a large forest cover in North Africa and along the Mediterranean basin which management is not fully developed and new forest tools are required. In this research, the forest structure, epidometric characteristics and allometric relationships were studied in 79 plots covering four bioclimatic zones from natural even aged forests of Aleppo pine located between eastern Algeria to the western coastal part of Tunisia. To characterize the forest structure three sampling methods were carried out: classical inventories (recording all pine trees), and two simplified approach using one average size or five dominant pine tree per plot. Annual growth increment and cone production were only calculated for the average size tree. Furthermore, the analysis of variance showed non-significant differences recorded between bioclimatic zones in trunk or crown diameter using the two simplified approach. Moreover, a significant decrease from wetter to drier areas in total height, crown height, cone seed production was observed only for average size tree method. However, the analysis of covariance showed significant differences between both approaches in total height, trunk diameter and crown coverage which were largely influenced by the pine tree density. In future investigations, we confirmed previous research that the dominant tree is a good sampling method to examine the site fertility, whereas the average size tree constitutes a valuable approach to study the population growth and reproduction.

Key words: *Pinus halepensis* Mill.; bioclimatic zones; forest structure; sampling approach; increment; reproductive characteristics.

Resumen

Métodos alternativos de muestreo para estimar la estructura y caracteres reproductivos de bosques de pino carrasco en Túnez

El pino carrasco muestra una gran cobertura forestal, tanto en el norte de África como en toda la Cuenca Mediterránea, cuyo manejo no está totalmente desarrollado lo que requiere nuevas herramientas de manejo. En esta investigación, se estudiaron la estructura forestal, las características epidométricas y las relaciones alométricas de 79 parcelas distribuidas a lo largo de cuatro zonas bioclimáticas en bosques regulares de pino carrasco situados entre el este de Argelia y la costa este de Túnez. Para caracterizar la estructura forestal se aplicaron tres métodos de muestreo: inventario clásico (midiendo todos los pies) y dos propuestas más sencillas, usando un árbol medio o cinco pies dominantes por parcela. El análisis de varianza no mostraba diferencias significativas de las mediciones de diámetro de tronco y de copa realizadas entre las distintas zonas bioclimáticas usando ambos métodos. Por otra parte, se observó una disminución significativa de las zonas más húmedas a las más secas en altura toral, altura de copa y producción de semillas fue observada aplicando el método de árbol medio. Además, el análisis de covarianzas mostraba diferencias significativas, usando ambas metodologías, en los valores medios de altura total, diámetro de tronco y cobertura de copa que mostraron estar influenciados por los valores de la densidad de arbolado de cada zona. Para futuras investigaciones, confirmamos estudios previos que apuntaban que la propuesta de muestreo de árboles dominantes como un buen método de muestreo para caracterizar la calidad de sitio mientras que la de árbol medio constituye una valiosa propuesta para el estudio del crecimiento de poblaciones y sus características reproductivas.

Palabras clave: *Pinus halepensis* Mill.; zonas bioclimáticas; estructura forestal; propuesta de muestreo; incremento; características reproductivas.

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Introduction

Mediterranean Basin ecosystems are disturbed by soil erosion, drought periods, night frost, summer heat and forest fires (Fernández and Tapias, 2005). In recent decades, climate change (higher aridity and longer drought periods) and its consequences, such as changes in fire dynamics, could induce a loss of vigor, productivity and alter reproductive dynamics, decreasing the ecosystem resilience (Moriondo *et al.*, 2006; Schiller and Atzmon, 2009). These effects have been found in Aleppo pine forest in the Mediterranean Basin (Sabaté *et al.*, 2002) and new tools are required to prevent and mitigate them. The development of new silvicultural tools for the adaptation of the classic silvicultural treatments have been developed in the western and northern area of the Mediterranean Basin (López-Serrano *et al.*, 2005; Moya *et al.*, 2008a, 2009) but not in the studied area.

Aleppo pine (*Pinus halepensis* Mill.) is one of the main forest tree species covering a high area along the Mediterranean Basin. According to the FAO (2001), along the northern African Basin a high forest surface is covered with natural or reforested Aleppo pine stands (about 850,000 ha in Algeria, 300,000 ha in Tunisia and 65,000 ha in Morocco). In this way, there is a general interest in this species in the Mediterranean Basin due to the importance of its ecological and protective characteristics, such as their wide distribution in addition to soil protection in areas where other species could not survive or carbon sink properties even in areas with low site quality (Montero *et al.*, 2001). This species is very important for both the economic role, such as timber and seed production promoting local employment, and for the ecological value, such as the high resilience and resistance (FAO, 2001).

The forest management has not been fully developed in North Africa and there is a lack of scientific knowledge about climatic influence on forest structure and tree growth. In this way, the national forest inventories have been classifying them according to forest structure or tree growth using stand level as the basic unit and the tree density as the recording parameter (Goreaud *et al.*, 2005). Attempting to achieve sustainable forest management in North Africa, long-term silvicultural management plans have been applied to most forests, although not all of them have been executed (Khouja *et al.*, 2000). The implementation of the management plans may have influenced the forest structure, development and competition (Bravo *et al.*, 2008; Moya *et al.*, 2009) varying the total height and trunk diameter (Fady *et al.*, 2003). In addition, the new natural recruitment could be affected by soil properties and the serotinous level of the stand (Goubitz *et al.*, 2003; Schiller and Atzmon, 2009).

P. halepensis have developed an early cone production showing strobila about five to seven years old (Climent *et al.*, 2008). The cone crop is affected by genetic and environmental factors, such as tree density, geographical parameters or climatic conditions (Moya *et al.*, 2008b). The tree growth has been quantified by sampling the dominant tree, which has been found to be not influenced by climate variables and stand characteristics in coniferous species (Wang, 1998). Also is common to use allometric relationships relating the biomass to non destructive measurements (stem diameter) but are depending on site and tree density (López-Serrano *et al.*, 2005). In northern Africa there are no allometric relationships developed for Aleppo pine and it could be an easy and economic tool to calculate several individual tree characteristics (stem volume and seed yield) providing useful information to characterize stands (Goreaud *et al.*, 2005) and improving the forest management implementation (Khouja *et al.*, 2000).The relevance of the fitting allometric equation is mandatory to estimate the productive and reproductive characteristics reducing errors (Ketterings *et al.*, 2001; Condes and Sterba, 2008).

In this study, we aimed at finding the best sampling alternative to calculate epidometric and reproductive characteristics for Aleppo pine forests and whether they are influenced by environmental parameters. Due to the recent increasing interest in Aleppo pine forest values, we provided to foresters an useful scientific information based on the comparison of two simplified tools to support decisions in forest management planning. Furthermore, we included an overview of tree growth, timber classification and reproductive characteristics of Aleppo pine forest in Tunisia. To achieve it, we focused on three main objectives:

i) To obtain an easy, quick and cheap sampling method to characterize the Aleppo pine stand.

ii) To calculate the allometric relationships linking total height, trunk diameter and age to useful tree characteristics for forest planning, taking into account climatic influences.

iii) To observe the changes in epidometric and reproductive characteristics in a bioclimatic gradient ranging Algerian border to eastern coast of Tunisia.

Material and methods

Study site

The study was focused on natural Aleppo pine forests distributed from eastern Algeria to the eastern coastal of Tunisia (Fig. 1). We obtained the study regions by projecting the geographical coordinates of every sample plot on the Bioclimatic and Phyto-ecological Map of northern Tunisia established by Gounot and Le Houerou (1967). They were located between the latitudes ranging 35.22° N to 36.50° N and the longitudes 8.33° E to 9.85° E. The altitudinal range in the study areas was 250 m to 1,185 m above sea level (a.s.l.). The total sampled area was covering 7.9 ha of forested surface grouped into four bioclimatic regions and 79 rectangular plots (Table 1). The soil types, in general, were calcareous and little evolved with colluvial and alluvial contributions but in the eastern study region we found predominantly red and clayish profiles. In central and western areas, we found both poor and degrade soils and dark grayish-brown calcareous clays. We located the plots in Aleppo pine stands characterized with red and clayish soils to reduce the variability of productivity coming from soils (Gaucherel *et al.*, 2008). The vegetation was composed of three strata (trees, shrubs and herbaceous) represented by Aleppo pine as the main tree species, being the essential accompanying vegetation species represented by *Tetraclinis articulata* Benth, *Juniperus phoenicea* L., *Quercus ilex* L., *Ceratonia siliqua* L., *Rosmarinus officinalis* L. According to the altitudinal rage we found in the upper *Erica multiflora* L., *Erinacea anthyllis* Link, *Retama sphaeroscarpa* L., *Artemisia herba alba* Asso, *Cistus libanotis* L., *Diplotaxis harra* (Forsk.) Boiss. Meanwhile, the companion vegetation in the lower altitudinal range was predominantly composed of *Juniperus oxycedrus* L., both *Pistacia atlantica* Desf and *P. lentiscus* L., *Olea europea* L., *Phillyrea angustifolia* L., *Cupressus sempervirens* L. and *Cistus monspeliensis* L.

The bioclimatic regions included the main geological, climatic, edaphic and structural characteristics of Aleppo pine stands in North Africa. The most important Mediterranean ombroclimates were included, from subhumid to lower semiarid, and the average annual precipitation ranged 625 to 423 mm. The Tunisian National Institute of Meteorology provided a database containing the values of the last 20 years from nearest weather stations to the sampled areas. The data provided from the Climate Observatories were interpolated (inverse distance weight) to obtain isotherms (each 1°C) and isohyets (each 25 mm) and each plot was

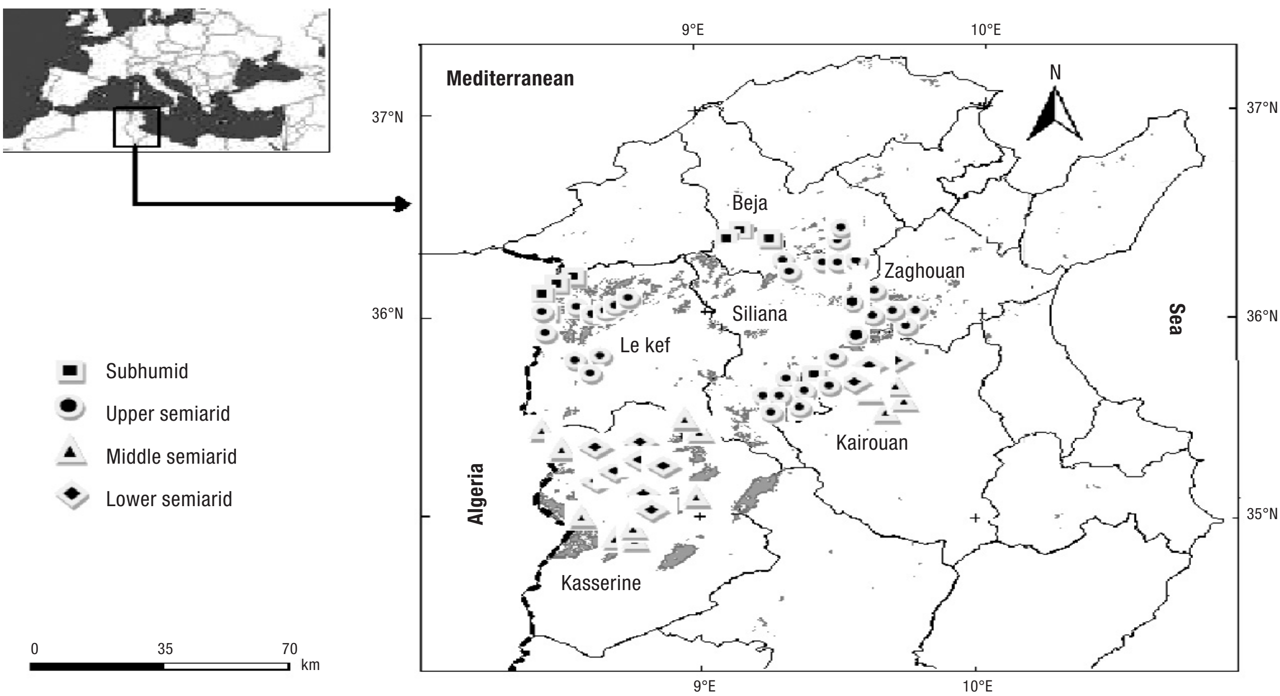

Figure 1. Map showing the different Mediterranean bioclimatic type characterizing the Tunisian forests of *Pinus halepensis* Mill., and the geographic location of all 79 plots used to sample cone and seed production in the summer of 2006.

Table 1. Soil description, geographic location and climatic data of the studied area in North African Aleppo pine forests under four bioclimatic zone

	Bioclimatic zones			
	S_H (n = 8)	**U_{SAR} (n = 35)**	**M_{SAR} (n = 22)**	**L_{SAR} (n = 14)**
Soil types and surface				
Pedology	Calcareous soil			
Red soil		Calcareous bed rocks	Rendzenic profile	
Surface (ha)	0.8	3.5	2.2	1.4
Geographic location				
Altitude (m, a.s.l.)	455-900	320-1,185	330-1,100	250-1,025
Latitude (°N)	36.32-36.54	35.22-36.50	35.48-36.42	35.17-36.22
Longitude (°E)	8.40-9.15	8.33-9.85	8.36-9.74	8.53-9.75
Climatic characteristics				
P_a (mm),	625	502	476	423
T_{Max} (°C),	33.2	32.3	33.1	33.9
T_{Min} (°C).	3.5	3.5	4.4	4.8

S_H: sub-humid. U_{SAR}: upper semiarid. M_{SAR}: middle semiarid. L_{SAR}: lower semiarid. P_a: mean annual rainfall. T_{Max}: maximum mean annual temperature. T_{Min}: minimum mean annual temperature.

assigned both values (averaged rainfall and temperatures) from the closer lines. These values from each plot were used to obtain the Ombroclimate index (I_0), calculated as ten times the quotient resulting value between the mean annual rainfall and the mean annual yearly temperature (Rivas-Martínez *et al.*, 1999). The ombroclimates or ombrotypes found were: S_H: Subhumid (7.00 < I_0 < 3.60); U_{SAR}: Upper Semiarid (3.59 < I_0 < 1.80); M_{SAR}: Middle Semiarid (1.79 < I_0 < 2.00); L_{SAR}: Lower Semiarid (1.99 < I_0 < 1.00). The plot distribution was proportional to the forest surface previously calculated for each bioclimatic zone since the most Aleppo pine forests were scatted in the semiarid zone. Finally, the 79 sample plots were located in the four ombroclimates, as follows: 8 plots were located in sub-humid (S_H) zones and 71 in semiarid zones, 35 plots in the upper semiarid (U_{SAR}), 22 in the middle semiarid (M_{SAR}) and 14 in the lower semiarid (L_{SAR}).

Epidometric measurements and data recording

The 79 rectangular plots (40 × 25 m; 0.1 ha) were set along the study area taking into account forest sampling procedures (Corona *et al.*, 1998; Newton, 2007; West, 2009). The selected Aleppo pine stands were chosen according similarities in biotic and abiotic characteristics, such as the forest health (no pest attacks), terrain aspect and soil type, to reduce the variability of non-included parameters influencing the productivity.

In 2004, all the Aleppo pine trees (7,686) located in the sample plots were counted and identified. We measured their total height (Ht) using an expandable pole and the diameter of the trunk at the breath height (DBH) with a caliper according Rondeux (1993). The Ht and DBH values averaged per plot to identify the overall current Aleppo pine forest structure. To achieve it, we used a classification based on the distribution of the Ht and the DBH frequencies according classical sampling inventory methodologies (Castagneri *et al.*, 2008). For each plot, we selected the individual pine tree more similar to the obtained average Ht and DBH; it was the average size tree (AST) per plot. In addition, the averaged values of the five taller pine trees were conformed to the dominant tree value (DT).

In 2005, the 79 AST and the 395 DT selected were marked and sampled in the field. Following Newton (2007) and Mailly *et al.* (2009), we recorded Ht, DBH and the crown diameter (CWD) for AST and DT in each plot. In addition, the crown height (CWH; using decameter) and age (Pressler borer) were recorded in the AST of each plot (Rondeux, 1993). This database was used again to categorize forest structure depending on the distribution of frequency in each bioclimatic.

Using Ht distribution depending on both sampling methods, we distinguished three classes of crown dominance (Reid *et al.*, 2003): the *overtopped* (suppressed trees with low vigor), the *codominant* (taller than overtopped but < 12 m) and the *dominant* layer (> 12 m).

Additionally, we developed allometric equations relating wood production (Stem volume), cone crop and seed yield. According Meredieu *et al.* (2003), we determined the mean annual Ht and DBH increase as indicators of tree growth. Also we obtained the forest canopy cover, representing the percentage of covered soil covered by the main tree species, calculated as the ratio of the canopy cover (using CWD) and the total sampled surface (Korhonen *et al.*, 2006; Garchi and Ben Mansoura, 1999). Moreover, we classified the tree size in three softwood categories (a_1: small wood size; a_2: medium wood size; a_3: large wood size) according to the diameter class methodology (Reque and Bravo, 2008). The estimation of stem volume over bark (SV) was calculated using the following formula (Matziris, 2000):

$$SV = \frac{\pi}{3}\left(\frac{DBH^2}{4}\right)Ht$$

were *DBH* = diameter at breast height and *Ht* = total height

Following Goubitz *et al.* (2002) and Moya *et al.* (2008a), we defined the current canopy seed bank as the viable seeds stored in the mature pine cones ripened in the current year (brownish, born for 3 years) and in the new serotinuous pine cones (grayish, born for 4 years). We estimated it by direct counting climbing to the pine trees. All the mature and serotinous cones born in AST were collected by the pine tree-climbers. The sampled pine cones (8890) were carried to the laboratory, counted, weighted and their length and width were recorded. The total volume of cones per stand was estimated by multiplying the average volume of cones (calculated using the cone formula) by the total number of collected cones per plot, differentiating mature and serotinous cones. After that, they were dried in an oven, at 80°C for a week, to open them avoiding seed damage (Moya *et al.*, 2008b). The seeds were manually extracted carefully, counted, weighted and separated in different sets according the cone type and the ombroclimate from they were sampled. The cone crop was calculated for each bioclimate by multiplying the mean number of mature and serotinous cones per plot and relating them to the pine tree density (Verkaik and Espelta, 2006). The current canopy seed bank was calculated for each zone by multiplying the cone crop and the mean number of seeds per cone, taking into account if they were mature or serotinous.

Statistical analysis

To describe the Aleppo pine forest structure, Ht and DBH class proportions were calculated using descriptive statistics. The wood size was characterized using the frequency distribution by DBH class (5 cm) and Ht class (2 m). We also developed linear regressions relating the values of DBH, Ht and CWD obtained from both sampling methods (AST and DT) and the pine tree density.

To check the Pearson's correlation coefficient (r), the values of the variables were log-scale, square root and inverse transformed before running the analysis, although they are shown without transformation. One-way ANOVA and Tukey's Studentized Range test were used to check significant differences in the measured variables into the four bioclimatic zones. To reduce and validate the number of variables and the number of individuals to sample, multivariate analyses and analysis of covariance (ANCOVA) were used to compare the regression models for overall, AST and DT for each response variable (Milliken and Johnson, 2002). According to the analysis of covariance the models can be written as:

$$y_{ij} = a_j + b\left(Log\left(Dsty\right)\right) + \varepsilon_{ij}$$

where: y_{ij}: variable (DBH, Ht or CWD) depending on the sampling method (*i* = AST or *i* = DT) in the sampled site *j*; a_i and *b:* the intercept and slope coefficients (respectively) estimated depending on the tree estimator; *Dsty:* Aleppo pine tree density; ε_{ij}: error term.

We looked for similar models for the independent variables, for both methods AST and DT, fitting the recorded data. Additionally, we obtained significant allometric relationships for North African Aleppo pine forests using multiplicative regressions which were the most common equation shape, $Y = aX^b$ (López-Serrano *et al.*, 2005). The statistical software package SAS version 9.1 was used to perform all the aforementioned procedures.

Results

We compared the overall values for the epidometric variables recorded in all pine trees in 2004. They were

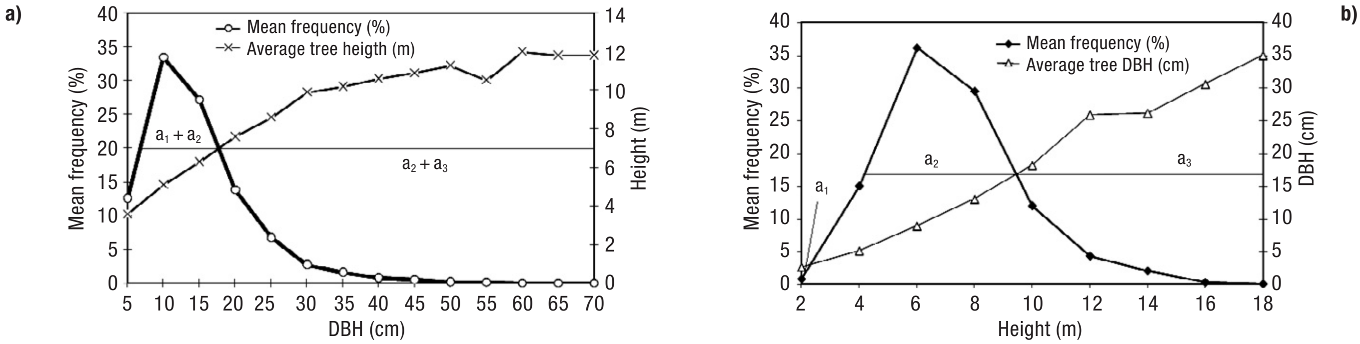

Figure 2. Mean frequency of diameter distribution of all sampled trees for diameter at breast height (DBH) and total height classes and their relationships for the Aleppo pine forests in North Africa. The polygons delimited by both lines intersection defined the wood size type (a_1: small, a_2: medium, a_3: large) in both ways: a) DBH class's distribution and mean total height; b) Total height distribution and mean DBH. *Note:* Open circles represented the mean frequency of DBH; Crosses represented the mean height; open triangles represented the mean frequency of total height; closed lozenges represented the mean DBH.

not showing significant differences with the averaged values obtained from the AST approach but were significantly lower than those obtained with DT methodology. Using them, we built the frequencies graphic using the mean frequency of DBH and Ht (Fig. 2). The distribution of frequencies of DBH (Fig. 2a) showed that 12.6% of the sampled pine trees presented DBH lower than or equal to 5cm which wood was negligible. The small and medium wood size ($a_1 + a_2$) was composed by pine trees with DBH ranging 10-30 cm and was conformed by 74.3% of the individuals sampled. The upper category, large wood size (a_3), was conformed by 3.2% of the stands covering the DBH classes from 30 to 70 cm. Related to Ht distribution Fig. 2b), we found that 84.2% of the pine trees were taller than 6 m but just 2.3% were reaching more than 12 m. A tiny percentage (0.8%) presented a total height lower than 2 m (a_1). The frequency of medium (a_2) and large (a_3) tree sizes were delimited by the intersection of Ht mean frequency and the averaged DBH for height class.

In the same way, we used values from AST and DT methods to determine the wood class size distribution and crown dominance for the four bioclimatic zones (Fig. 3). The small and medium wood sizes were found to be comprised in the 10 to 30 cm DBH classes according the classical inventory what was applied to both alternative methods. The AST (Fig. 3a) and DT (Fig. 3b) distributions showed 98.7% and 74.7% of Aleppo pine trees had an average DBH from 10 to 30 cm ($a_1 + a_2$), respectively. The mean frequencies recorded for the highest wood size (a_3), according to the DBH classes from 30 to 45 cm, were 1.3% and 25.3% for AST and DT, respectively. Regarding to Ht distribution to obtain the classes of crown dominance, we distinguished more than 98.7% of the pine trees included in the classes from 6 to 12 m height (I + II), overtopped and codominant pine trees, using the AST method (Fig. 3c). These crown classes were composed with 88.6% of pine trees sampled with DT approach (Fig. 3d). The dominant class (III) was composed by 1.3% and 11.4% of Aleppo pine trees depending on the method (AST and DT, respectively).

According to the bioclimatic zones (Table 2), we obtained the parameters related to the three methodologies. Forest canopy cover and pine tree density obtained from the classic inventory (recorded in 2004) were showing no significant differences. The analysis of covariance determined that forest canopy cover and pine tree density were not significantly related ($r = 0.198$, $p > 0.079$) and CWD was showing not significant differences (in both methods). The highest for both parameters was found in U_{SAR} (0.37 ± 0.14 and $1{,}054 \pm 82$ pine trees ha^{-1}) and the lowest for canopy cover was in M_{SAR} (0.28 ± 0.14), meanwhile the lowest pine tree density was in L_{SAR} (804 ± 116 pine trees ha^{-1}). The parameters related (DBH, Ht and CWH) significantly related to DT characteristics were not showing significant differences in the four bioclimatic zones. The DBH estimated from DT, varied between 22.75 ± 1.80 cm recorded in S_H and 25.99 ± 2.00 cm found in M_{SAR}. On the contrary, we found the lowest Ht in L_{SAR} (8.76 ± 0.45 m) and the highest in S_H (10.75 ± 0.79 m). Indeed, the CWD values ranged from 5.06 ± 0.27 m in the U_{SAR} to 6.31 ± 0.58 m recorded in the S_H. The significant parameters related to the AST approach were DBH, CWD, stem volume and the annual increase of Ht and DBH which were not significantly different depending on the bioclimatic

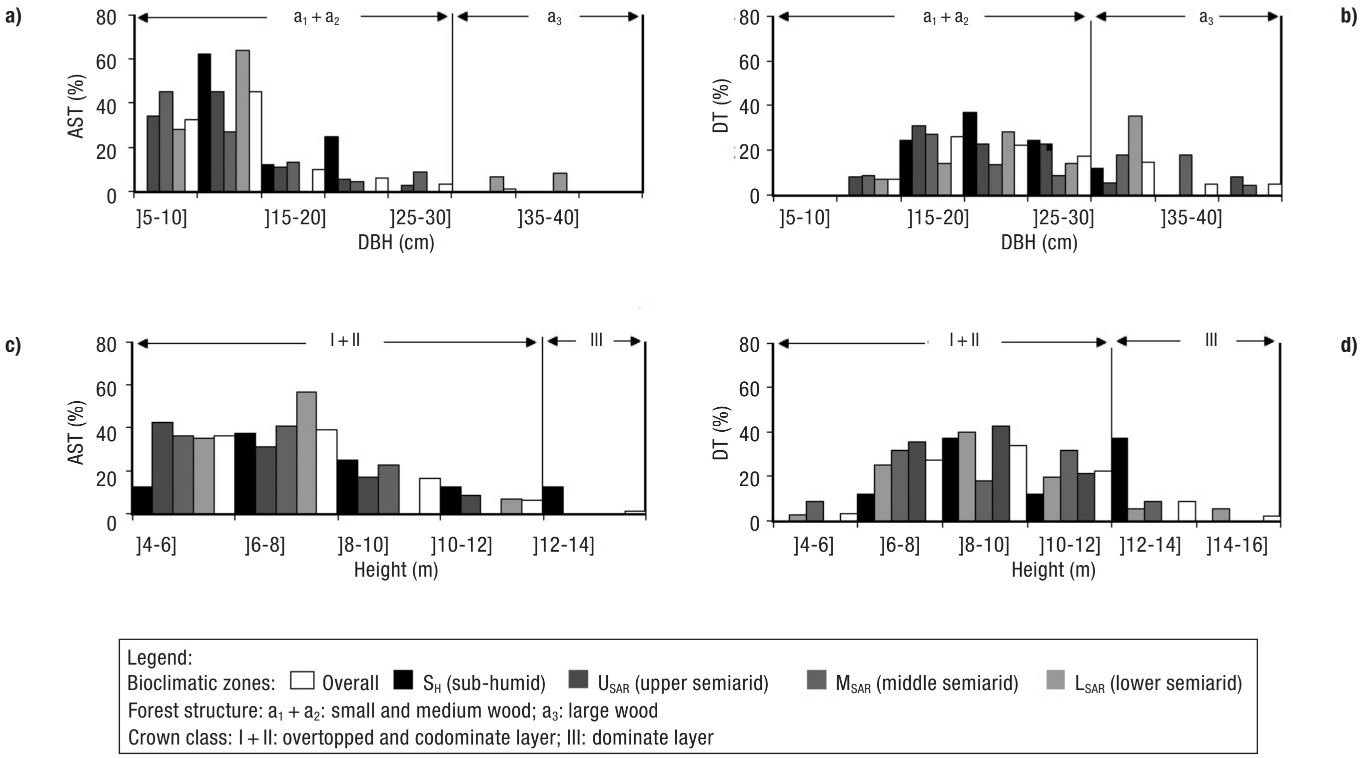

Figure 3. Determination of Aleppo pine forest for structure and crown classes in four bioclimatic zones in Southern Mediterranean Basin using the recordings coming from average size tree (AST) or dominate tree (DT) by DBH class (a and b) or by height class (c and d).

zone. Wood stem volume ranged among bioclimatic zones from 38.2 ± 1.0 m^3 ha^{-1} in the U_{SAR} to 75.1 ± 22.0 m^3 ha^{-1} in the S_H. No significant differences in the annual increase for the DBH or Ht using AST as growth estimator have been identified. The annual increase for DBH was ranging 3.0 ± 0.3 mm yr^{-1} (in L_{SAR}) to 3.8 ± 0.3 mm yr^{-1} (in S_H), meanwhile annual increase for Ht varied between lower mean values obtained in the L_{SAR} (15.6 ± 1.6 cm yr^{-1}) and higher mean values recorded in the S_H (20.0 ± 1.5 cm yr^{-1}). The reproductive characteristics (cone production and seed yields) in addition to basal area, Ht and CWH, were significantly related to the AST method and showed significant differences. In this way, we used them to characterize the bioclimates, being the highest values in S_H (11,7036 ± 15,987 cone ha^{-1}, 199.22 ± 25.80 kg ha^{-1}, 17.36 ± 1.65 m^2 ha^{-1}, 8.83 ± 0.84 m and 5.64 ± 0.68 m, respectively). The cone production was decreasing according decreasing site quality, showing significantly lowest crops and volume in L_{SAR} (5,4376 ± 8,502 cone ha^{-1} and 1,622 ± 233 m^3 ha^{-1}). However, no significant differences between semiarid subzones were found for basal area, total height, crown height, cone volume and seed yield.

Relating variables obtained from both sampling methodologies, we obtained several allometric relationships (Table 3). The allometric relationships for Ht-DBH (R^2 = 0.634), Ht-age (R^2 = 0.337), DBH-age (R^2 = 0.469), CWH-DBH (R^2 = 0.705) and CWD-DBH (R^2 = 0.710) showed higher correlation coefficients and explained more variability than those found with DT values, such as Ht-DBH (R^2 = 0.469), CWD-DBH (R^2 = 0.554) and CWD-Ht (R^2 = 0.368). However, the models found for reproductive characteristics related to DBH were showing lower efficiency. They were significant and were explaining 0.422, 0.340 and 0.360% of variability included in allometries relating cone size, cone number and seed weight to DBH, respectively.

We validated the characterization of crown dominance classes previously obtained, using the significant allometric relationships for both methods (Fig. 4). We related the recorded pine tree density to the modeled DBH, Ht and CWD values from allometric relationships which were significant for both recording methods (DT and AST). The obtained curvilinear relationships were showing negative tendencies for both methods. Moreover, we carried out an analysis of covariance which showed not significant differences in the slope

Table 2. Mean values, standard error and significant differences between groups (superscripts) for stand characteristics and average (AST) and dominant (DT) tree characteristics (reproductive characteristics, Epidometric and annual increment values) in native Aleppo pine forests in North Africa

	Bioclimatic zones			
	S_H (n = 8)	U_{SAR} (n = 35)	M_{SAR} (n = 22)	L_{SAR} (n = 14)
Stand characteristics				
Canopy cover (%)	32.5 ± 9.2[a]	37.4 ± 14.3[a]	27.4 ± 13.8[a]	34.5 ± 13.3[a]
Density (pine trees ha^{-1})	869 ± 95[a]	1054 ± 82[a]	890 ± 89[a]	804 ± 116[a]
Basal area (m^2 ha^{-1})	17.36 ± 1.65[a]	12.01 ± 0.84[b]	11.61 ± 1.07[b]	8.84 ± 1.25[b]
AST characteristics				
DBH (cm)	16.54 ± 1.56[a]	12.80 ± 0.77[a]	13.29 ± 1.23[a]	12.98 ± 1.66[a]
Ht (m)	8.83 ± 0.84[a]	6.89 ± 0.31[b]	6.58 ± 1.23[b]	6.43 ± 1.66[b]
CWD (m)	3.87 ± 0.23[a]	3.87 ± 0.23[a]	3.92 ± 0.31[a]	3.76 ± 0.34[a]
CWHt (m)	5.64 ± 0.68[a]	3.83 ± 0.22[b]	3.90 ± 0.25[b]	3.81 ± 0.32[b]
Age (year)	45.4 ± 5.0[a]	43.8 ± 3.1[a]	43.6 ± 4.4[a]	46.5 ± 5.4[a]
DT characteristics				
DBH (cm)	22.75 ± 1.80[a]	23.27 ± 1.28[a]	25.99 ± 2.00[a]	25.78 ± 1.79[a]
Ht (m)	10.75 ± 0.79[a]	9.32 ± 0.39[a]	9.18 ± 0.53[a]	8.76 ± 0.45[a]
CWD (m)	6.31 ± 0.58[a]	5.06 ± 0.27[a]	5.75 ± 0.46[a]	6.09 ± 2.52[a]
Annual increase for AST				
DBH (mm yr^{-1})	3.8 ± 0.3[a]	3.1 ± 0.1[a]	3.4 ± 0.4[a]	3.0 ± 0.3[a]
Ht (cm yr^{-1})	20.0 ± 1.5[a]	17.1 ± 1.1[a]	17.2 ± 1.5[a]	15.5 ± 1.6[a]
Stem volume (SV) and reproductive characteristics for AST				
SV (100 m^3 ha^{-1})	75.1 ± 22.0[a]	38.2 ± 1.0[a]	42.3 ± 10.1[a]	42.8 ± 21.0[a]
Cone volume (100 m^3 ha^{-1})	15.89 ± 3.83[a]	15.67 ± 4.01[a]	17.82 ± 3.09[a]	16.22 ± 2.33[b]
Cone production (cones ha^{-1})	117,036 ± 5,987[a]	105,912 ± 9,551[a]	8,9620 ± 8,656[a]	54,376 ± 8,502[b]
Seed yield (kg ha^{-1})	199.22 ± 25.80[a]	110.73 ± 9.39[b]	110.66 ± 11.22[b]	88.11 ± 16.98[b]

S_H: sub-humid. U_{SAR}: upper semiarid. M_{SAR}: middle semiarid. L_{SAR}: lower semiarid. DBH: diameter at breast height. Ht: total height, SV: stem volume. CWD: crown diameter. CWHt: crown height.

Table 3. Allometric relationships and model efficiency for the recorded variables using the average size and dominate tree values for Aleppo pine forest in North Africa

Trees approach	$y = a\,x^b$				Model efficiency	
	y	x	a	b	R^2	Pr > F
I. *Average size tree (AST)*	Ht	DBH	1.564	0.580	0.634	0.0001
	Ht	age	1.473	0.412	0.337	0.0001
	DBH	age	0.950	0.700	0.469	0.0001
	CWHt	DBH	0.734	0.663	0.705	0.0001
	CWD	DBH	0.737	0.645	0.710	0.0001
	Cone size	DBH	0.013	1.117	0.422	0.0001
	Cone Number	DBH	7.875	1.029	0.340	0.0001
	Seed Weight	DBH	8.905	1.058	0.360	0.0001
II. *Dominant tree (DT)*	Ht	DBH	1.695	0.538	0.469	0.0001
	CWD	DBH	0.462	0.781	0.554	0.0001
	CWD	Ht	0.949	0.795	0.368	0.0001

DBH: diameter at breast height. Ht: height.. CWHt: crown height. CWD: crown diameter.

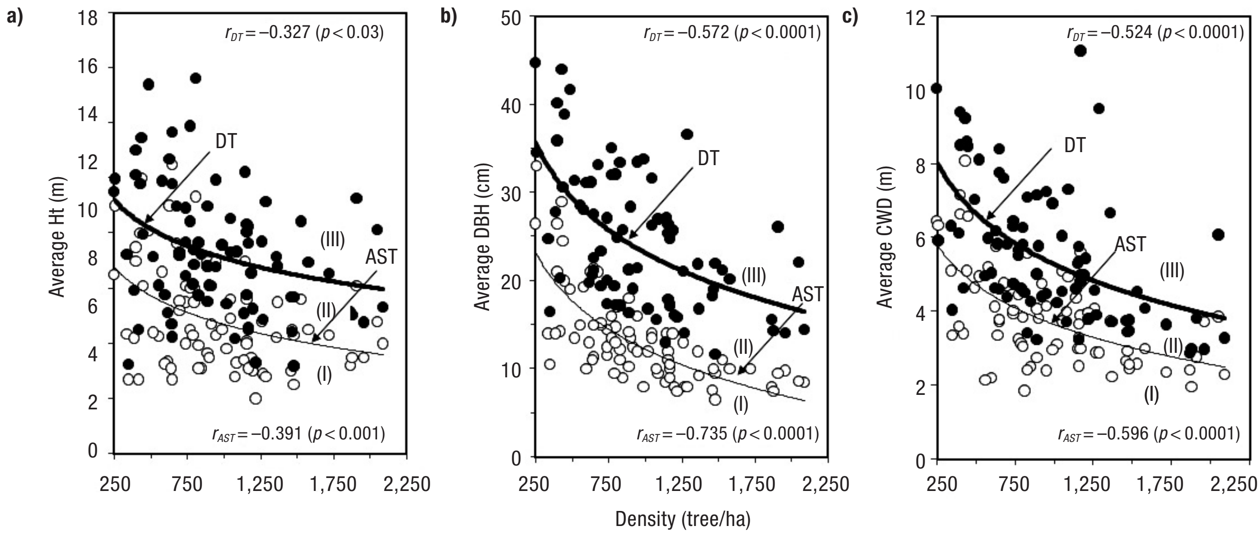

Figure 4. Influence of Aleppo pine tree density (x) on total height (Ht) (a), trunk diameter at breast height (DBH) (b), in addition to the crown diameter (CWD) (c). [Closed circles represent the dominate tree records (DT) and open circles represents the average size tree records (AST)].

values for the obtained regression lines. The significant differences for curves, obtained with different sampling methods, were found to be in the interception point. It generated three regression lines which conform the predictive models to obtain Ht [1], DBH [2] and CWD [3].

$$Ht = 17.153\left(I_{AST}\right) + 19.563\left(I_{DT}\right) - 1.5125\left(Log\left(Dsty\right)\right) \quad [1]$$

$$DBH = 70.687\left(I_{AST}\right) + 81.758\left(I_{DT}\right) - 8.470\left(Log\left(Dsty\right)\right) \quad [2]$$

$$CWD = 15.820\left(I_{AST}\right) + 17.518\left(I_{DT}\right) - 81.766\left(Log\left(Dsty\right)\right) \quad [3]$$

whereHt: total height; DBH: diameter at breast height; CWD: Crown diameter; Dsty: Aleppo pine tree density:

$$I_{AST} \begin{cases} = 1 \text{ if AST} \\ = 0 \text{ otherwise} \end{cases} ; \quad I_{AST} \begin{cases} = 1 \text{ if DT} \\ = 0 \text{ otherwise} \end{cases}$$

Discussion

Previous studies of pine species have been focused on many reproductive characteristics, such as cone abortion and pollen production (Goubitz *et al.*, 2002), seed dispersal capacity (Benkman, 1995; Lanner, 1998) and serotiny (Goubitz *et al.*, 2004; Moya *et al.*, 2008b). They were taking into account related factors influencing the variables measured but we found significant relationships with epidometric variables, bioclimates and sampling methods for Aleppo pine forests located in the southern Mediterranean Basin. Previous local studies, covering narrower areas, characterized the potential mature Aleppo pine forest in North Africa conformed to pine trees wider than 30 cm in DBH and taller than 12 m (Garchi and Ben Mansoura, 1999). We pointed that it was dependant on the geographical distribution and the total pine tree density, such as the case of isolated pine trees or open stands with low light and water competition (Castagneri *et al.*, 2008).

The information to calculate productivity and growth increases patterns was obtained from the AST method which was including a high rate of variability. Both variables were decreasing significantly according a latitudinal and climatic tendency, southwards from wetter to drier climatic zones. It confirmed the interaction of climatic factors, pine tree density and the availability of resources which was confirmed in populations in Spain (Moya *et al.*, 2007) and Israel (Goubitz *et al.*, 2002). In addition, significant negative relationship linking pine tree density to cone crops and seed yield has been found in the same study area (Ayari *et al.*, 2010). We found significant differences for reproductive characteristics related to bioclimates, as a direct consequence of water and nutrient availability which are influencing the number of reproductive pine trees and cone abortion (Goubitz *et al.*, 2004; Verkaik and Espelta, 2006; Moya *et al.*, 2008a). Depending on the main objective of management (timber or seed production), Aleppo pine stands should be thinned before the onset of severe intra-specific competition (De las Heras *et al.*, 2007). The Aleppo pine stands developed in optimal habitats showed higher tree growth, not only in DBH or Ht, but also in the production of branches and pine needles, which induce increase in the leaf area index as was proved for *Pinus sylvestris* (Vacchio *et al.*, 2008). In adittion, the higher cone production was not found in the higher trees (Climent *et al.,* 2008) but it was found in those areas where pine trees were maintaining a higher crown surface (although the crown height was lower).

The forest management must be based on scientifically knowledge and transmitted to managers, foresters and stakeholders in order to reach optimal stand structure in the present and the future to maximize the forestry planning to predict current problems such as, fire risk and global warming (Moya *et al.*, 2007, 2009). In this study, we found that AST and DT methods were representing averaged values for the stand level. Both approaches were found to be useful to characterize the forest structure, by using both Ht and DBH class distributions, which confirmed the relationship of epidometric parameters to the position in the crown dominance but not to site (Reid *et al.*, 2003). Combining simple regression of the AST and DT estimations to analysis of covariance (ANCOVA), we detected the limits for wood size and crown dominance depending on pine tree density. The AST and DT methods were fitting to represent the reproductive characteristics and the class fertility, respectively. Indeed, Ht and DBH distributions of AST values were used to calculate growth, meanwhile the low sensitivity of DT to thinning intensity was advising it against a good predictor (Rondeux, 1993). In this way, we recommend the AST sampling approach to estimate the seed yield and wood production in a similar way that for other pine species (Wittwer, 1997). However, we confirmed DT measurements fit as a good site quality estimator (Wang, 1998) and that were characterizing the pine tree intra-specific competition (Castagneri *et al.*, 2008). The implementation of new tools in forest management helps to the development of Forest planning, especially in North Africa. However, in future research, the estimation of both groups, stand parameters determined by using AST sampling or site quality approach coming from DT measurements, should include pine tree size stratification to produce unbiased predictions to take into account climate change, mainly in semiarid areas (De Luis *et al.*, 2009). Moreover, the two sampling approach methodologies were confirmed as easier and cheaper estimators for natural Aleppo pine forests in southern Mediterranean Basin which have been described as more vigorous in growth and fructification than northern or eastern populations (Climent *et al.*, 2008). Furthermore, Vennetier *et al.* (2008) proved that *P. halepensis* was well adapted to the studied climatic zones and the obtained significant differences were supporting studies carried out in Tunisia (Khouja *et al.,* 2000), Algeria (Harfouche *et al.*, 2003; Bentouati and Bariteau, 2005) and Morocco (Belghazi *et al.* 2000). Finally, the complexity of climatic influences on pine tree density resides in the structural and spatial distribution of pine trees (Vilà *et al.*, 2003; Condés and Sterba 2008). It would be necessary to perform a general study on climate change and its impacts on natural forests in order to develop and apply silvicultural management tools adapted to the new scenarios and problems (Sabate *et al.*, 2002), focusing on new objectives in sustainable forest management.

Conclusion

Individual tree growth models are important tools for forest management. They are supplied with allometric relationships which are influenced by site, age and management. The proposed alternative sampling methods could be implemented to speed up the recording of variables in forest inventories (growth, productive and reproductive characteristics) with a lower economical cost. In forest planning, the forest structure can be characterized by wood class according to the distribution of the Ht or DBH classes obtained from both AST and DT, although AST proved to be more efficient. The site quality was evaluated in a more representative way by DT approach. For future researches, we advice to use the AST method to calculate the cone crop, seed yield, growth increase and wood size distribution, whereas the DT sampling fit site quality and pine tree intra-specific competition.

The new tool is based on decreases in the complex and economical costs of forest inventories, reducing samplings to one average size or five dominate pine trees per plot to characterize the stand. The wood class distribution contributes to an easier development of the structural stand classification for Aleppo pine forests as a basic tool for typological inventories. Using AST as a sampling approach for stand characteristics, softwood categories and crown types can be easily defined. Using DT as a complementary sampling method, large softwood with medium size appears as one of the main characteristics of Aleppo pine forests in Tunisia. The methodology presented in this study describes an easy way to characterize forest wood distribution, forest canopy cover and growth. We also obtained some allometric relationships for North African Aleppo pine forest which could be useful tools.

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