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Study of the dynamics of natural stands of *Pinus halepensis* in the Beni Oudjana forest (Khenchela, Algeria)

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ABSTRACT

Knowledge of population structure and spatial distribution is an indispensable step in the sustainable management of forest stands. This study consists of analyzing these parameters of *Pinus halepensis* populations in the Beni Oudjana forest. Subjective sampling on the basis of the main exposures of the forest (North, East, South and West) allowed the establishment of inventory plots of 500 m². Dendrometric measurements (diameter at 1.30 cm, total height, barrel height, total volume) on individuals with a diameter greater than or equal to 5 cm at 1.30 m from the ground were carried out in sixteen plots. The highest density (2010 individuals/ha) and the lowest values of diameter (9.8±11.9 cm), basal area (0.01±0.04 m^2/ha) and total volume (0.2±0.8 m^3) were obtained within the plots with western exposure. Analysis of diameter and height structures revealed an increase in the frequency of young trees in the plots with western exposure. This work, which provides an overview of the state of the floristic diversity of the Beni Oudjana forest, allows taking appropriate measures to safeguard our plant resources.

Key words : *Pinus halepensis, Algeria, Forest Ecology*

Introduction

The forest of Beni Oudjana is one of the most important natural forests of Aleppo pine in the semi-arid zones of the Algerian Saharan Atlas. In the face of the desertification that threatens the lands of northern Algeria, this forest represents the last natural barrier against the advance of the desert. The Aleppo pine (*Pinus halepensis* Mill.) is one of the most widespread species in the Mediterranean region, covering more than 25 000 km² of forest formations in semi-arid and dry sub-humid regions (Quézel, 2000). It is dominated by its stands distributed in the form of large massifs throughout northern Algeria and inhabits even the most hostile areas of the steppe at the margins of the Sahara. Aleppo pine covers 35% of the forested areas of northern Algeria, i.e. around 800 000 ha (Bentouati *et al.*, 2005). It is located largely in its natural state in the eastern and central regions of the country, mainly on the Tellian and Saharan Atlas Mountains. The main forests are distributed on the ridges of the Saharan Atlas between 1000 and 1500 m altitude (Kadik, 1986). Pine forests form important forests with variable ecological values (Quézel, 2002).

Forest stands, whether natural or planted, monospecific or multi-species, even-aged or uneven-aged, young or old, have typical structures (characteris-

tics). It is known that the diameter structures of this forest stand types fit into known theoretical distributions (Kudus *et al.*, 1999; Husch *et al.*, 2003; Rennolls and Wang, 2005). Thus, the use of theoretical models is necessary in order to detect possible deviations from the stand type structures and thus to infer the stand life status.

Several studies have focused on the dendrometry of this species in Algeria (Bentouati *et al.*, 2005), highlighting a diversity of stands according to land use types and climate (Brochiero *et al.*, 1999). The complementary study we conducted aimed to specify the demographic structures of *P. halepensis* stands in the Beni Oudjana forest and to determine the effect of exposure on their numbers and regeneration.

Materials and Methods

Study area

The study was carried out in the Beni Oudjana forest, which is part of a forest and pastoral area of the Aurès massif (eastern Algeria) located between longitude (X1 : 6°58′07", X2 : 6°42′34") and latitude (Y1: 35°28′22", Y2 : 35°19′04"). Its specific diversity generally consists of Aleppo pine (*Pinus halepensis*), holm oak (*Quercus ilex*), juniper (*Juniperus oxycedrus*), juniper (*Juniperus phoenicea*), mastic pistachio (*Pistacia lentiscus*), narrow-leaved filbert (*Phillyrea angustifolia*) and rosemary (*Rosmarinus officinalis*). The climate of this forest massif is characterized by a long, dry and hot summer season and an increasing number of years with less rainfall. Rainfall is generally low and irregular. The rainfall gradient decreases from north to south. Mean annual temperatures range from 13.6 to 14.9 °C. The thermal regime is relatively homogeneous (Bentouati, 2006). From a bioclimatic standpoint, most of the pine forest has a north and northwest orientation and is located in the sub-humid stage during cold winters. The southern slopes are characterized by prolonged insolation and increased water deficit. It is, in fact, a continental climate. The study region is characterized by altitudes ranging from 950 meters to 1700 meters and steep slopes exceeding 25%.

Data Collection

The study plots were randomly selected in relation to the different cardinal exposures (East, South, West and North). Vegetation data were collected in rectangular plots of 25m × 20m (500m^2). Within each plot, the diameter at breast height (DBH, i.e. 1.30 m from the ground) was measured for all species including DBH ≥ 5cm (Mahamane and Saadou, 2008). The total height was measured using Bloom Lies on individuals of characteristic and valuable forest species by diameter class and plot. This positioning made it possible to highlight the spatial distribution of trees in the study area. The densities of the trees on the upper floor were obtained by simple counting.

Data Analysis

To analyze stand ecological characteristics, stand density (N), basal area (G) and total volume (V) were calculated. The density N (trees/ha) is the number of trees per unit area (Goba *et al.*, 2019). Basal area G (m^2/ha) is the sum of the cross-sections at 1.30 m above the ground level of all trees (Rabiou *et al.*, 2015).

The calculated data were analysed using MINITAB 18 software. One-factor analyses of variance (ANOVA) were used to compare the means of the Aleppo pine dendrometric parameters in the different plots. Significant ANOVA tests were followed by the paired multiple comparison Fisher test at the 5% significance level. Data that did not follow a normal distribution according to the Ryan Joiner test were compared using the nonparametric Kruskal Wallis test (Rondeux, 1999).

Demographic structure

The demographic structure of the species was analyzed according to tree diameters, defined from a threshold of 5 cm and amplitude of 5 cm. The height was defined from a threshold of 1.30 m, with an amplitude of 2 m. These diameter and height classes were used to construct distribution histograms. The observed structures were fitted to the theoretical three-parameter Weibull distribution using MINITAB 18 software (Rondeux, 1999; Goba *et al.*, 2019). The corresponding probability density function f(x) has the following form:

$$f(x) = \frac{c}{b}(x - a/b)^{c-1} \quad exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

Where: x is the diameter of the trees, (a) is the position parameter, (b) is the scale or size parameter, and (c) is the shape parameter related to the observed structure. The distribution can take sev-

eral forms depending on the value of the shape parameter (c) (Glèlè *et al.,* 2016); with c the shape parameter (or slope of Weibull) related to the structure under consideration, and b the scaling parameter related to the central value of the probability distribution of the variable x = diameter. A value of c < 1, reversed J distribution is characteristic of multispecies or uneven-aged stands, while a value of c > 3.6 is characteristic of stands with predominantly older individuals. On the other hand, if 1 < c < 3.6, this indicates stands with a predominance of young or small-diameter individuals.

Results

Structural characteristics of Aleppo pine populations

Aleppo pine densities range from 430 individuals/ha on north-facing plots to 2010 individuals/ha on west-facing plots (Table 1). The mean diameter of the trees of this species varies very significantly (P<0.000) depending on the exposure of the plots studied. It varies from 9.8±11.9 cm for the western exposure to 17.6±17.5 cm for the northern exposure. The basal area is very small for stands with western exposure (0.01 ± 0.04 m²/ha), whereas it is much larger for stands with southern exposure (0.06 ± 0.1 m²/ha). Thus, the analysis of variance test (ANOVA) carried out on the values obtained for height shows a very highly significant difference for the different exposures (P < 0.000). The highest values of total height and tree stem height are 9.2±6.4m for plots with northern exposure and 7.5±7.7 m for stands with southern exposure, respectively.

The mean total volume is greater on south-facing plots where it is estimated to be 0.8 ± 1.8 m³ compared to west-facing plots (0.2±0.8 m³). Stands with northern exposure are characterized by the largest values of mean diameter (17.6±17.5 cm) and total height (9.2±6.4 m) while stands with southern exposure are characterized by the largest values of basal area (0.06±0.1 m²/ha) and total volume (0.8±1.8 m³) (Table 1). On the other hand, the minimum values of mean diameter (9.8±11.9 cm), basal area height (0.01±0.04 m²/h) and total volume (3±1.2 m³) are found in the western exposure plots.

The Kruskall Walis statistical test is significant (P<0.000) for diameter, basal area, total height, barrel height and total volume between plots in the forest massif.

Population structure of natural stands of *P. halepensis*

Diameter structure of stands

The distribution of trees in diameter classes shows a different situation depending on the four exposures (Fig. 2). For stands exposed to the west and south, the distribution of trees by diameter shows an inverted J-shape with a shape parameter c taking a value less than 1. This structure is therefore regressive and characteristic of natural stands with high regeneration potential, reflecting a regular population dynamics of *P. halepensis.* The two northern and eastern exposures show a distribution with a shape similar to an "L" curve, with a shape parameter c=1. This exponentially decreasing distribution centred on the diameter class [10-20 cm], characteristic of populations with high regeneration potential but presenting a problem of survival during the transition between stages of development.

Height structure of *P. halepensis* populations

The distribution of the inventoried trees by total height classes at 2m amplitude according to plot exposure is shown in Figure 3. The graphs show an asymmetric bell-shaped distribution shifted to the right and centred on the height class (2 to 4m) for the northern exposure and (2 to 8 m) for the trees in these east-facing plots. This right asymmetry indicates the predominance of young individuals in the stand; parameter c of the Weibull distribution is equal to 1. This right asymmetry poses a problem of recruitment of young individuals in the classes of

Table 1. Dendrometric characteristics

Exposition	N/ha	DHP (cm)	G (m²/ha)	Ht (m)	H b (m)	V (m³)
North	430±105^{c}	17.6±17.5^{a}	0.04±0.08^{ab}	9.2±6.4^{a}	3.3±1.6^{b}	0.5±0.9^{ab}
East	725±132^{b}	17.3±14.1^{a}	0.03±0.05^{b}	8.6±5.4^{a}	4.2±2.4^{b}	0.3±0.7^{b}
South	755±435^{b}	17.2±23.8^{a}	0.06±0.1^{a}	7.5±7.7^{a}	3.8±2.4^{b}	0.8±1.8^{a}
West	2010±1390^{a}	9.8±11.9^{b}	0.01±0.04^{c}	7.6±7.8^{a}	6.7±4.6^{a}	0.2±0.8^{b}
ANOVA	0.000	0.000	0.000	0.3	0.000	6.789

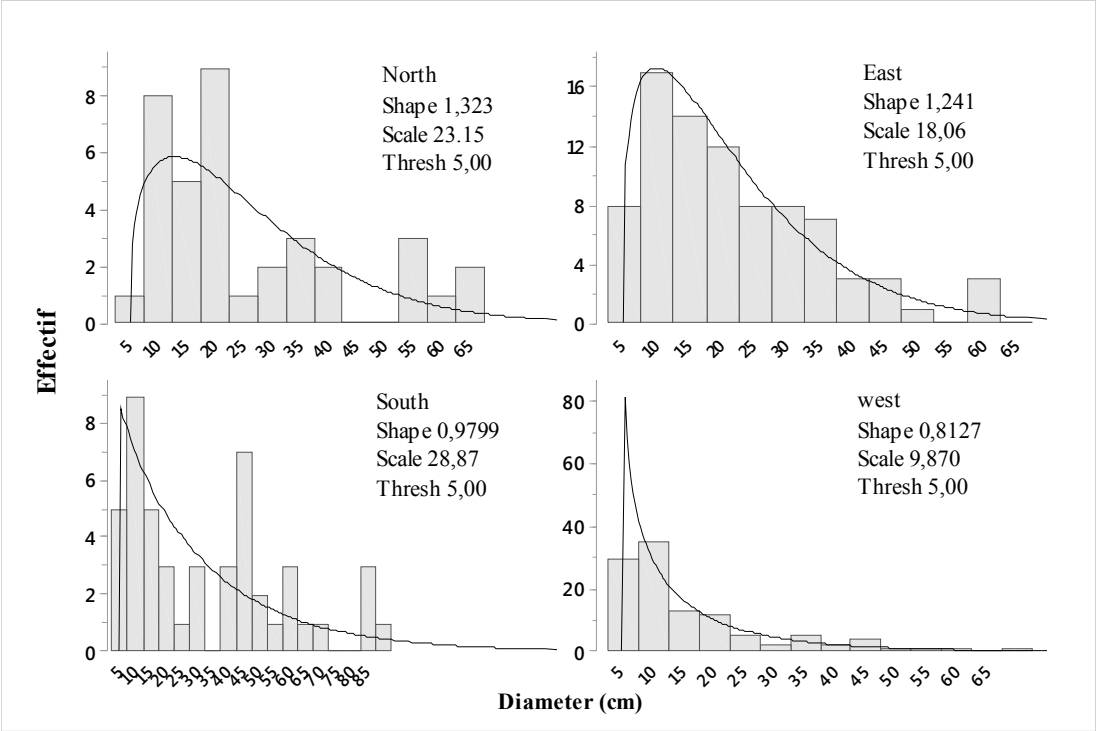

Fig. 2. Diameter structure of Aleppo pine stands.

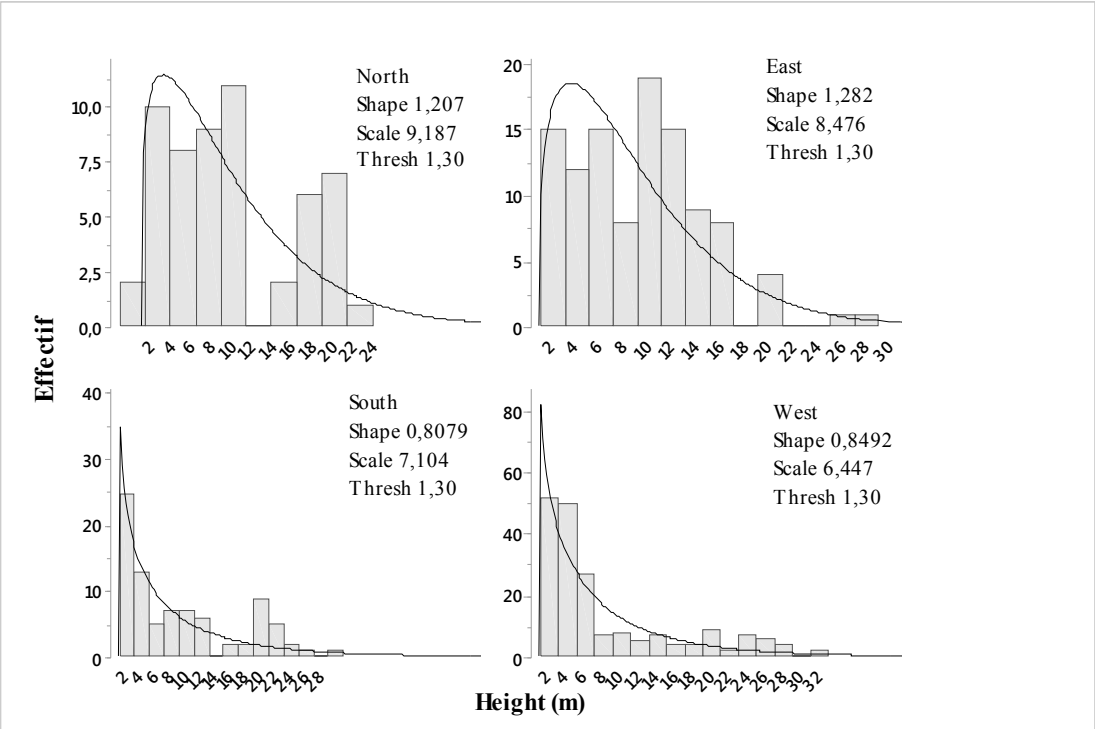

Fig. 3. Height structure of Aleppo pine groupings.

older individuals and thus constitutes a decision support tool for the forester in forest stand management (Husch *et al.,* 2003). In contrast, in stands exposed to the south and west, the tree distribution has an inverted J-shape with a shape parameter c of the theoretical Weibull distribution taking a value of less than 1. This structure is therefore regressive and characteristic of natural stands with high regeneration potential, reflecting a regular population dynamics of *P. halepensis*.

Discussion

Structural characteristics are major indicators for measuring the qualitative and quantitative evolution of forest stands (Oosterhoon and Kapelle, 2000). Aleppo pine stand density is higher on the western exposure of the Beni Oudjana forest (2010 stems per hectare) compared to other exposures. The difference in stand density could be related to the ecological characteristics of the study environments, including soil types, topography, climate, cover and especially the altitudinal gradient (Rabiou *et al.,* 2015). *P. halepensis* stands are subject to grazing, which is the main activity of the local population on the northern and eastern slopes; this permanent anthropogenic action may also justify the difference in density between the different exposures. The negative impact of the various anthropic pressures exerted on the *P. halepensis* forest stands in the Beni Oudjana massif has long been recognized. Human activities such as logging, animal husbandry, agriculture, uncontrolled expansion of dwellings, fires cause the destruction of forest ecosystems and the disappearance of forest species.

A significant difference is noted for measured structural characteristics (mean diameter, basal area and barrel height) between *P. halepensis* populations based on the exposure of the study plots. Our results reveal that large diameters and dominant tree heights are in the north-facing plots. This observation can be explained by the predominance of older individuals. The low values of mean diameter, basal area and total volume of trees observed in the western exposure plots indicate the high frequency of young trees.

The structures in diameter and height of the natural stands show a predominance of young individuals ($c<1$; $1 < c < 3.6$) for the different exposures of the Beni Oudjana forest. Diameter structures, established on the basis of the distribution of individuals in diameter classes (5-10cm), are characterised by a large number of small trees and a steady reduction in the number of individuals from one class to the next. In addition, the demographic structure of trees in height classes reveals a predominance of medium-sized trees (2-8 m). These structures show a positive evolution of *P. halepensis* stands in this massif where stand renewal is ensured (Feeley *et al.,* 2007) due to its extraordinary expansion power and low requirements (Quezel, 1986; Bentouati, 2006).

Conclusion

This study allowed the dendroecological characterization of natural stands of *Pinus halepensis* in plots at different exposures of the Beni Oudjana forest. High density and good regeneration are assigned to the plots with western exposure. This forest is characterized by the dominance of small diameter individuals and large diameter individuals are almost absent. Comparison of dendrometric parameters between stands in the Beni Oudjana Massif shows that exposure favors better growth of Aleppo pine. The densities of young trees are relatively high on the western slope, where thinning must be carried out for harmonious development. The results of this research constitute a descriptive and analytical diagnosis that deserves to be extended to other Aleppo pine forests in semi-arid zones in Algeria in order to obtain more information on the behaviour of this species and to propose silvicultural treatments to ensure better protection of natural pine forests that have been threatened for several decades.

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