Biodiversity Journal, 2022,13 (4): 877–883 https://doi.org/10.31396/Biodiv.Jour.2022.13.4.877.883

The effect of phytoecological factors on the natural regeneration of Aleppo pine (*Pinus halepensis* Miller, 1768) in semi-arid zones

Belkacem Daoudi[1*], Kouider Cherifi[1], Fathi Abdellatif Belhouadjeb[2] & Amar Khadoumi[3]

[1*]Laboratoire de Biodiversité Végétale: Conservation et Valorisation, Université Djillali Liabès, BP89, Haï Larbi Ben M'Hidi, Sidi Bel Abbés 22000, Algeria; e-mail: belkacem.daoudi@univ-sba.dz; cherifi.kouider@yahoo.com
[2]Centre de Recherche en Agropastoralisme (CRAPAST), Djelfa, Algeria; e-mail: belhouadjebfathi@gmail.com
[3]Laboratoire Exploration et valorisation des écosystèmes steppiques (EVES), Faculté des Sciences de la Nature et de la Vie, Université Ziane Achour, Djelfa, Algeria; e-mail: amar.khadoumi@gmail.com
*Corresponding author, e-mail: belhouadjebfathi@gmail.com

ABSTRACT The aim of our study is to define the factors influencing the natural regeneration of Aleppo pine (*Pinus halepensis* Miller, 1768) in the Mediterranean forest, particularly in the most important forest (massif of Senalba Chargui) in Algeria, characterized by its semi-arid climate. Stratified and subjective sampling are adopted in our work; stratified sampling makes it possible to obtain representative stations for the various existing ecological situations. We divided our study area into 4 stations according to the massif, the slope exposure and the type of the soil. For every station, subjective sampling method is used to install temporary observation plots; we installed in our study stations seventy (70) temporary plots, and the plot is a circular sampling unit that covers an area of 400 square meter. In each plot, a phytoecological survey was carried out to determine the environmental parameters, such as altitude, the slope exposure, lithology, anthropic influence (pasture and cutting); as well as other factors related to the structure of the vegetation, such as the second and third dominant species, overall and per-stratum cover and the elements of the soil cover. We used principal component analysis (PCA) to identify the homogeneous sample plots (compared to the regeneration), descriptive statistics, and the correlation coefficient. The number of seedlings per square meter varies between 0 and 0.23, and there are several factors affecting these results.

KEY WORDS Aleppo pine; Algeria; natural regeneration; phytoecological; semi-arid.

Received 08.07.2022; accepted 22.11.2022; published online 30.12.2022

INTRODUCTION

The Aleppo pine (*Pinus halepensis* Miller, 1768), by its forest cover - over than 3.5 million hectares - its remarkable plasticity and its socio-economic role, is considered an essential component of the Mediterranean forest and represents a capital of great value for most of Mediterranean countries (Quézel & Barbéro, 1992). Currently, many natural and reforestation Mediterranean forests are in imbalance, many dieback areas have been noticed in recent years. This degradation is the result of the reduction of natural regeneration, the fragility of ecosystems and the loss of biodiversity.

In Algeria, the Aleppo pine covers 35% of the wooded areas of northern Algeria (Kadik, 1983), it

is approximately 800,000 ha (Bentouati et al., 2005). The Algerian climax forests of this species are located in the semi-arid and lower sub-humid bioclimatic stages; the Aleppo pine is largely located in its natural state in the eastern and central regions of the country mainly in the Atlas, Tellien and Saharan (Louni, 1994).

The region of the high plains of southern Algiers and the Saharan Atlas is subject to a climate characterized by a long summer season, often very dry, and to pressures due to human action (Dahmani, 2018). The natural regeneration of the Aleppo pine, like some other Mediterranean species, is facing serious problems (Calama & Montero, 2007); it is difficult and very insufficient in the Saharan Atlas, leading several forests to a process of degradation.

The aim of our study is to define the phytoecological factors influencing the natural regeneration of Aleppo pine in a natural forest process (not to appropriate silvicultural interventions), in the pine forest of Senalba Chargui. This forest, found in one of the massifs of the central Saharan Atlas, is considered one of the most beautiful pine forests (Louni, 1994) and the most important in Algeria (Boudy, 1950) and constitutes the last southern refuge of the range of this species.

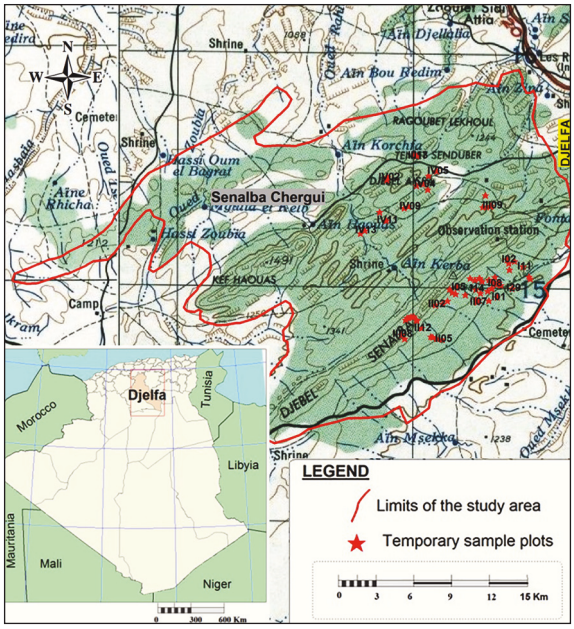

Figure 1. The study area: Senalba Chargui = Senalba East forest in Algeria.

MATERIAL AND METHODS

Study area

The Senalba Chargui forest constitutes one of the main natural Aleppo pine forests in the semi-arid zones of the Saharan Atlas in Algeria (Fig. 1). This national forest is located 2 Km west of the city of Djelfa (300 Km south of Algiers), it covers an area of 20,000 Ha (hectare) and the altitude is between 1190 m and 1450 m. The regional bio-climate is Mediterranean semi-arid with a cold winter (Emberger, 1971), rainfall is around 310 mm (millimeter) and the average temperatures are between 26 °C (Degree Celsius) in July and 5.4 °C in January. The precipitation regime is of the A.P.H.E type (autumn, spring, winter, summer); two classes of soils are noted for Senalba: Rendzines and calcareous brown soils (Kadik, 2005).

Sampling

The sampling adopted in this work is stratified and subjective. Stratified sampling makes it possible to obtain representative stations for the various existing ecological situations. We divided our study area into 4 stations according to the massif, the slope exposure and the type of the soil; and for every station, temporary observation plots are installed through subjective sampling. This method is used to study heterogeneous ecological environments.

We have installed in our study stations seventy (70) temporary plots (Table 1). The temporary sample plot is a circular sampling unit that covers an area of 400 m^2.

Choice of indicators

The indicator used for the Aleppo pine regeneration phenomenon is the regeneration index, this index is the number of seedlings per square meter. Considering that the regeneration of Aleppo pine in semi-arid zones is episodic (irregularity and variability of precipitation), we considered as juveniles all the pines with their DBH (Diameter at Breast Height) less than 10 cm; after the evaluation of this indicator in each plot, we classified them according to their numbers and their heights (Table 2).

The phytoecological study reflects the combina-

tion, or the relationships between vegetation and ecological factors, which play an active role in their distribution and development. There are three phases of the study; the first is to determine the types of vegetation, then to identify the active factors of the environment, and the last one to identify species-factor links (Kadik & Godron, 2004). In each plot, a phytoecological survey was carried out to determine the environmental parameters, such as altitude, the slope exposure, lithology, anthropozoic influence (pasture and cutting); as well as other factors related to the structure of the vegetation, such as the second and third dominant species, overall and per-stratum cover and the elements of the soil cover.

We used the principal component analysis (PCA) and the analysis of variance (ANOVA) to identify the homogeneous sample plots (compared to the regeneration). It should be noted that all statistical analyses (descriptive statistics, the correlation coefficient) were made with "Statistica 8". The geographical data was mapped using the software "MapInfo 11".

RESULTS AND DISCUSSIONS

Aleppo pine regeneration is low to zero in more than 54% of the plots studied (group C) (Fig. 3), and it is average in more than 15% of the plots, and only in 30% of plots the regeneration is very good to good with rates respectively equal to 21.42% and 8.57%. More than 87% of the plots have no seedlings and the others (more than 11%) have seedlings between one and four, only one plot with a high seedling value equal to 32 (group B) (Fig. 3); 10% of the studied plots have seedlings of 25 cm, and more than 25% of all the plots have seedlings of 50 cm; more than 41% of the plots have seedlings of 50-100 cm with a number varies between one and fifty seedlings; and between one and eighteen seedlings of 100-150 cm are found in more than 42% of the plots. More than 38% of the plots have seedlings of 150 cm to 200 cm and seedlings from 200 cm to 300 cm are found in 30% of the plots studied; therefore the regeneration index varies between 0.0 to 0.23 plants per square meter.

The stands most represented in our sampling are in the age group between 80 and 120 years, in general are even-aged stands, with a rate of 45% of all the plots studied; and followed by older stands, over 120 years old and can reach more than 180 years with a rate of 37%. The least represented stand (<2%) is where the age is between 30–40 years. The age group of 60 to 120 years is collected over 86% of the plots where the regeneration is very good and 50% of the class of good regeneration; contrary to the oldest stands (over 120 years) where more than 61% of the plots have low regeneration; this is explained by the low productivity of the seeds. The analysis of variance (ANOVA) indicates that there exists a significant effect of stand age on Aleppo pine regeneration, with the age range from 80 to 120 years encompassing the highest regeneration indexes (Fig. 4).

To assess the health status of Aleppo pine, we studied the number of plants with diebacks in the plot, yellowing of leaves and defoliation. Aleppo pine in the Senalba Chargui massif is generally in good condition, however, more than 72% of the plots are in good to very good condition and only 5.7% are in out of condition. The Aleppo pine in out of condition regenerates very poorly, 100% of the stands have no regeneration where the Aleppo pines were in poor health; this situation is due to the mediocre quality and quantity of seeds produced by bad pines trees.

The studied plots are characterized by an altitu-

Station	Number of sample plots	Massif	Slope exposure	Location
ST01	29	Senalba Chargui	South	Mazreb Elali South
ST02	13	Senalba Chargui	South	Elbeida
ST03	14	Senalba Chargui	North	Mazreb Elali North
ST04	14	Senalba Chargui	North	Nakazia

Table 1. Geographic characteristics for each study station.

Classes by number		Classes by height	
None	0	1	Seedling
Low	1-5	2	25 cm
Average	6-10	3	25-50 cm
Good	11-20	4	0.5- 1 m
Very good	>21	5	1-2 m
		6	2-3 m

Table 2. Classification of pine juveniles (number and height).

dinal slice of 1184 m to 1391 m. The statistical results show that there is no significant relationship between the regeneration of the Aleppo pine and the altitude of the studied plots.

The northern "ubac" slope of Senalba Chargui represents the best regenerations of Aleppo pine with a rate of over 45% where the regeneration has been good to very good, and 30.9% of the plots have low or no regeneration; on the contrary, the southern slope "adret" represents more than 61% of the plots have low or no regeneration, and only 23.4% where the regeneration was good to very good. Kadik (1983) observed in the same massif (Senalba Chargui) that the temperature differences between the North and South slopes can exceed 8°C, and the difference between the two exposures is accentuated during the cold period of the year from October to April, and it is unimportant during the dry period.

The regeneration is positively proportional with the rate of the tree cover and the shrub cover; where the heights are between 0.6 m to 2 m the correlation coefficient is equal to r = 0.34, and for heights from 2 to 4m the correlation coefficient equal to r = 0.28; Pardos et al. (2007) demonstrate that for low to moderate light intensities, herbaceous vegetation has minimal impact on the germination and emergence of pine seedlings. The growth of vegetation and seedlings is then positively correlated with the increase in light. For higher light intensities, the development of interfering vegetation is always positively related to the lighting, but over time it becomes too dense and inhibits the development of pine seedlings. The negative effect of competition on pine seedlings is only noticed for high light intensities (Noemie, 2010).

The overall vegetation cover is the projection of the cover of shrub and herbaceous strata in the studied plots, it is between 15% and 85% with an average of 55.15%, these cover rates are positively correlated with regeneration (r = 0.26). This relationship is because of the advantageous role of this covering to protect young seedlings and seedlings against direct sunlight and mitigate the effects of high temperatures.

The litter cover, in its integral composition, has no relationship with the natural regeneration of Aleppo pine; but the rate of twigs shows a positive correlation with the regeneration index (R = 26). Twigs can limit vegetation competition and evaporation through the mulching effect (Johansson et al, 2006), and also, they can offer to young seedlings a shelter favoring a microclimate (Castro et al., 2011). It should also be noted that there is a non-apparent opposite action between the fraction of twigs and those of leaves, explained by the low negative correlation between the regeneration and leaf cover rate (r = -19). Fernandez et al. (2008) and

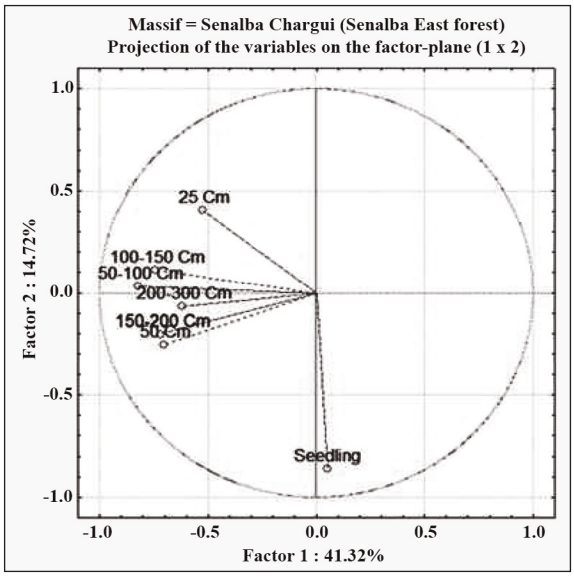

Figure 2. The principal component analysis (PCA) (variables).

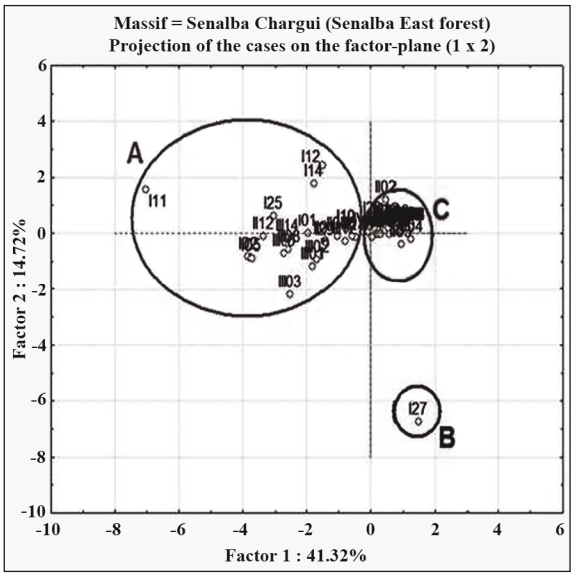

Figure 3. The principal component analysis (PCA) (sample plots).

Bonin et al. (2007) show that there is autotoxicity induced by allelochemicals present in Aleppo pine leaves that affect the germination and growth of its seedlings.

Sheep pasture is more dominant in the forest of Senalba Chargui. It was intense and very intense in 63.85% of the studied plots, and this rate is very minimal in 5.7% of the plots where pastures was low but not zero. Pine regeneration was low or non-existent in 57.57% of the plots that were subjected to intense pasturage, and over 63% of the plots that were subjected to very intense pasturage; 75% of the plots where pasturage is low show good to very good regeneration. The analysis of variance shows that the intensity of pasture has a negative significant effect on the regeneration of Aleppo pine (Fig. 5). Pasturage, especially in the period of shortage, stripped the shrub strata, reduced the quality of the soil (trampling, erosion, etc.), and consequently, it reduces the receptivity of the soil for regeneration, thus, it promotes the establishment of thermophytic species, especially poaceae, which is very competitive for Aleppo pine seedlings.

We evaluated the cut by the number of stumps present in the plots. Cutting trees in the forest of Senalba is necessary to clean the forest of dead subjects after a dieback or because of various ailments, but not for a type of oriented plan. Cutting was important or very important in 58.57% of the plots studied, and it is low in 14.28% of the plots, 40% of the plots where regeneration is very good are plots characterized by significant cuts, significant cuts are also noted in 66.67% of the plots where regeneration is good. Cutting decreases the density and competition of adult crowns, and creates holes which favors Aleppo pine regeneration if other conditions are favorable.

The Aleppo pine and *Juniperus oxycedrus* L. grouping represents 57.14% of the totality of the plots studied (physiognomic dominance in 2nd order of *Juniperus oxycedrus* after Aleppo pine); followed by the groups of Aleppo pine with *Cistus libanotis* L. and Aleppo pine with *Juniperus phoenicea* L. with a rate of 12.85% for each group. The other groupings of Aleppo pine with other species - *Stipa tenacissima* L., *Quercus ilex* L., *Phillyrea angustifolia* L., *Rosmarinus tournfortii* (Noë ex Jord. & Fourr.) Jahand. & Maire, 1898 and *Globularia alypum* L. - represent only minimal percentages varying between 1.42%and 4.28%.

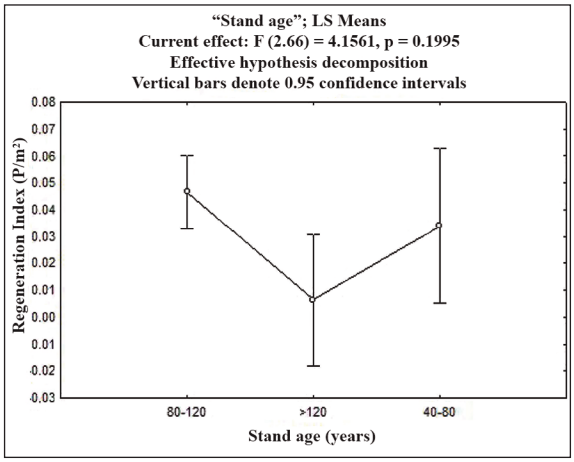

Figure 4. The effect of stand age on the regeneration of Aleppo pine.

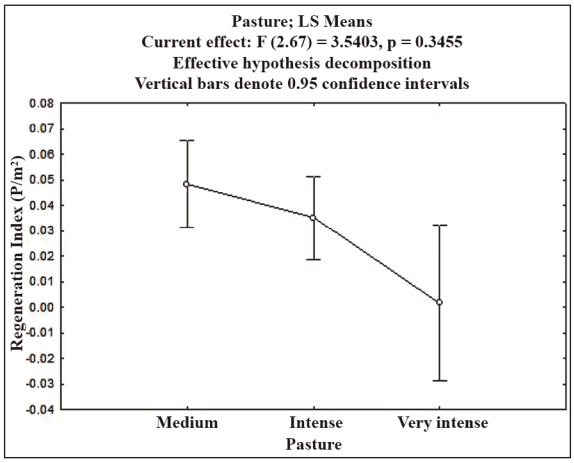

Figure 5. Effect of pasture on the regeneration of Aleppo pine.

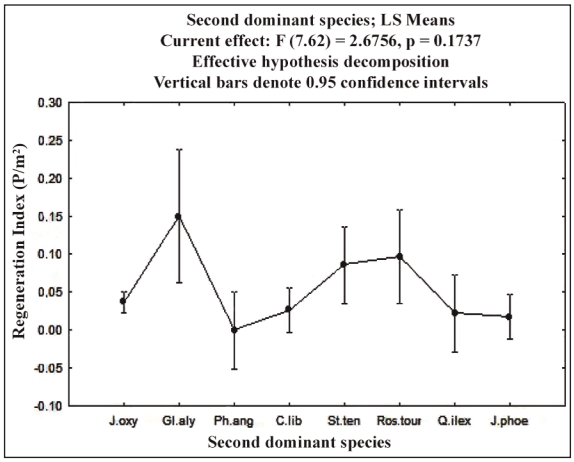

Figure 6. The potential of natural regeneration of Aleppo pine in different vegetation groups.

The most dominant species in 3rd order with the Aleppo pine is *Stipa tenacissima* L. with a frequency of 44.28%, followed by *Cistus libanotis* L. and *Phillyrea angustifolia* L. with a rate of 25.70% and 7.14% respectively; the other species - *Juniperus phoenicea* L., *J. oxycedrus* L., *Pistacia lentiscus* L., *Cistus villosus* L., *Ampelodesma mauritanicus* (Poir.) T. Durand & Schinz and in last position *Rosmarinus tournefortii* De Noé - are less represented with rates varying between 1.42% and 5.71%. The analysis of variance shows that there exists a very significant difference between the various plant groups regarding the potentiality and the natural regeneration capacity of Aleppo pine (Fig. 6). The *Pinus halepensis*, *Juniperus oxycedrus* grouping is contributed by more than 60% of the plots where regeneration is very good, and by 50% in the class of good regeneration. Of the plots of *Pinus halepensis* groups with *Cistus libanotis*, 66.66% of them have low to no regeneration. This rate (66.66%) is observed in the group of *Pinus halepensis* with *Juniperus phoenicea* and the group *Pinus halepensis* with *Quercus ilex*. The *Pinus halepensis* with *Rosmarinus tournefortii* and *Pinus halepensis* with *Globularia alypum* L. groups are less represented in our study (3 plots in total) where the quality of regeneration is very good.

CONCLUSIONS

The objective of our work was to analyze the effects of ecological and anthropogenic parameters on the natural regeneration of Aleppo pine (*Pinus halepensis*) in the forest massif of Senalba Chargui (Djelfa in Algeria) characterized by in a semi-arid climate. The regeneration index varies between 0 and 0.23 seedlings/m^2, and 60% of the plots studied have low or no regeneration. The microclimate, provided by the northern slope, is more favorable to the regeneration of Aleppo pine compared to the circumstances of the southern slope. The regeneration of Aleppo pine is successful in an open environment (not smothered) and supported by trees in vigorous condition and an age between 60 to 100 years. Moderate covers by shrubs and twigs have advantageous effects for regeneration; they protect young seedlings and contribute to the inhibition of establishment of therophytes, especially Poaceae, which are very competitive for seedlings. Concerning anthropogenic pressure, pasturage is a perpetual threat to regeneration; on the contrary, cutting is an action that could promote regeneration by creating holes. The ecological environment, including the dynamics and the structuring, of *Pinus halepensis* groupings with *Juniperus oxycedrus*, or with *Rosmarinus tournifortii* or with *Globularia alypum* is the most favorable for the regeneration of Aleppo pine.

REFERENCES

Bentouati A., Oudjehih B. & Alatou D., 2005. Croissance en hauteur dominante et classes de fertilité du pin d'Alep dans le massif de OuledYakoub et des Beni Oudjana (Khenchela- Aurès). Sciences & technologie. C, Biotechnologies, 23: 57–62.

Bonin G., Bousquet MA., Lelong B., Bousquet-Melou A., Lelong B., Voiriot S., Nozay S. & Fernandez C., 2007. Expansion du pin d'Alep. Rôle des processus allélopathiques dans la dynamique successionnelle. Forêt méditerranéenne, 28: 211–218.

Boudy P., 195. Économie forestière nord-africaine: II. Monographie et traitement des essences forestières. Larose, Paris, 877 pp.

Boudy P., 1955. Économie forestière nord-africaine: IV. Description forestière de l'Algérie et de la Tunisie. Larose, Paris, 877 pp.

Calama R. & Montero G., 2007. Cone and seed production from stone pine (*Pinus pinea* L.) stands in Central Range (Spain). European Journal of Forest Research, 126: 23–35.

Castro J., Allen C.D., Molina-Morales M., Marañón-Jiménez S., Sánchez-Mirand Á. & Zamora R., 2011. Salvage logging versus the use of burnt wood as a nurse object to promote post-fire tree seedling establishment. Restoration Ecology, 19: 537–544.

Dahmani M.M., 2018. État des connaissancessur les systèmes forestiers d'Algérie / State of knowledge on forest systems in Algeria. Ecologia Mediterranea, 44: 111–117.

Emberger L., 1971. Travaux de botanique et d'écologie. Éd, Masson et Cies., France, 520 pp.

Fernandez C., Lelong B., Vila B., Mévy J P., Robles C., Greff S., Dupouyet S. & Bousquet-Mélou A., 2006. Potential allelopathic effect of *Pinus halepensis* in the secondary succession: an experimental approach. Chemoecology, 16: 97–105. https://doi.org/10.1007/s00049-006-0334-z

Fernandez C., Voiriot S., Mévy JP., Vila B., Ormeno E., Dupouyet S. & Bousquet-Mélou A., 2007. Regeneration failure of *Pinus halepensis* Mill.: the role of au-

totoxicity and some abiotic environmental parameters. Forest Ecology and Management, 255: 2928–2936.

Gounot M., 1969. Méthodes d'étude quantitative de la végétation. Masson, Paris, 314 pp.

Hikmat A., Barbero M. & Loisel R., 1984. Réflexions sur le dynamisme actuel de la régénération naturelle du pin d'Alep (*Pinus halepensis* Mill.) dans les pinèdes incendiées en Provence calcaire (de 1973 à 1979). Ecologia mediterranea, 10: 85–104.

Johansson K., Örlander G. & Nilsson U., 2006. Effects of mulching and insecticides on establishment and growth of Norway spruce. Canadian Journal of Forester Search, 36: 2377–2385. https://doi.org/10.1139/x06-121

Kadik A.L., 2005. Étude phytosociologique et phytoécologique des formations à pin d'Alep (*Pinus halepensis* Mill.) de l'étage bioclimatique semi-aride algérien. USTHB, Algerie, 341 pp.

Kadik B., 1983. Contribution à l'étude du Pin d'Alep (*Pinus halepensis* Mill.) en Algérie: écologie, dendrométrie et morphologie. Faculté Aix-Marseille III, France, 364 pp.

Kadik L. & Godron M., 2004. Contribution à la dégradation dans les pineraies de *Pinus halepensis* Mill. Journal de Botanique, Société botanique de France, 27: 9–19.

Louni D., 1994. Les forêts algériennes. Forêt méditerranéenne, 15: 59–66.

Noemie G., 2010. Interactions pour la lumière entre les arbres adultes, les jeunes arbres et la végétation du sous-bois au sein d'un écosystème forestier: application à la régénération du pin sylvestre en peuplement mélangé chêne sessile - pin sylvestre. Université d'Orléans, France, 194 pp.

Pardos M., Montes F., Aranda I., Pardos M., Montes F., Aranda I. & Cañellas I., 2007. Influence of environmental conditions on germinant survival and diversity of Scots pine (*Pinus sylvestris* L.) in central Spain. European Journal of Forest Research, 126: 37–47. https://doi.org/10.1007/s10342-005-0090-6

Quézel P., Barbero M. & Akman Y., 1992. Typification de syntaxa décrits en région méditerranéenne orientale. Ecologia mediterranea, 18: 81–87.

Quezel P. & Santa M., 1962. Nouvelle flore de l'Algérie et des régions désertiques méridionales. IGN, Paris, 2 voll., 1165 pp.

Tsitsoni T., 1997. Conditions determining natural regeneration after wildfires in the *Pinus halepensis*(Miller, 1768) forests of Kassandra Peninsula (North Greece). Forest Ecology and Management, 92: 199–208.

Tsitsoni T. & Zagas T., 1995. Development of *Pinus halepensis* natural regeneration in Kassandra Chalkidiki. Scientific Annals of the Department of Forestry and Natural Environment, 1: 93–103.

Tsakaldimi M.N., Tsitsoni T.K., Zagas T. & Ganatsas P., 2004. Aleppo pine (*Pinus halepensis*) natural regeneration, without fire, in the Kassandra Peninsula, northern Greece. Ecology, conservation and management of Mediterranean climate ecosystems: proceedings of the 10th International Conference on Mediterranean Climate Ecosystems, April 25 - May 1, 2004, Rhodes, Greece, pp. 1–8.