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Biomass, radial growth and regeneration capacity of Aleppo pine, and its possible use as rootstock in arid and degraded areas

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This paper reviews recent findings on Aleppo pine (*Pinus halepensis* Mill.), which is found throughout the Mediterranean region and has been introduced in several areas of the world. This species is used in reforestation efforts for timber production and protection of degraded areas. Several studies have shown that this species has high biomass productivity and high plasticity. Its radial growth is influenced by the climate and the physical environment. Aleppo pine is known for its great capacity for expansion in its natural environment and its great capacity for invasion in areas where it has been introduced worldwide. The use of *P. halepensis* Mill. as rootstock has yielded satisfactory resultsin the production of stone pine cones and nuts in marginalized, arid, and dry areas. This review can help forest managers developing optimal management strategies for Aleppo pine stands in arid and sub-arid Mediterranean regions.

Keywords: *Pinus halepensis* Mill., Biomass, Radial Growth, Regeneration, Grafting, Arid Land

Introduction

Aleppo pine (*Pinus halepensis* Mill.) is a widespread tree species whose natural range is limited to the Mediterranean basin (Quezel & Barber 1992 – Fig. 1). In total, it covers an area of approximately 3.5 million hectares of natural and reforested stands (Quezel 1980, Neeman & Trabaud 2000). Aleppo pine is well represented in the mountainous massifs of the Maghreb countries, where it spreads over 65,000 ha in Morocco (in the Rif, and the Middle and High Atlas) and 370,000 ha in Tunisia (DGF 2010 – Fig. 2). In Algeria, the species covers 35% of the wooded areas in the north, that is, approximately 800,000 ha (Bentouati et al. 2005). Aleppo pine is mainly found as natural stands in the eastern and central regions of the country, mainly in the Tellian and Saharan Atlas Mountains. The main forests are distributed on the ridges of the Saharan Atlas at altitudes between 1000 and 1500 m a.s.l. (Kadik 1987).

In Europe, the largest area covered by Aleppo pine forests is on the Mediterranean coast of Spain, where it forms pure stands of 1,046,978 ha and covers 497,709 ha in mixed stands with other species (Montero et al. 2001). In France, *P. halepensis* is found on the limestone hills of the coastal zone from Nice to the Italian border, with a surface area of 202,000 ha (Couhert & Duplat 1993). In Italy, Aleppo pine is not very abundant (~20,000 ha), but it may be found in large populations in Southern Apulia and in a few localities in Sardinia and Sicily.

Aleppo pine is one of the most common species in the Mediterranean region, where it forms stands generally found at low altitudes (< 500 m a.s.l.) and along the coasts (Elaieb et al. 2017) in dry and warm environments (Neeman & Trabaud 2000). In Aleppo pine forests, nutrient cycling is influenced by litterfall and silvicultural practices (Segura et al. 2019). The species is characterized by a high production of seeds with a great capacity of natural dispersion, thus favoring the regeneration and expansion in suitable habitats. In Northern Africa, management practices seek to improve the seed and wood productivity of Aleppo pine trees (Jaouadi et al. 2019). Indeed, Aleppo pine seeds are widely consumed in North Africa (Jaouadi et al. 2019) and are used in the preparation of creams and cakes in many Arab countries. In addition, juice made from fermented seeds is used to prepare a traditional pudding (Minervini et al. 2020). Therefore, the production of Aleppo pine seeds represents an important issue for the sustainable development and improvement of living standards of the people relying on these resources. Further, through the marketing of its seeds, Aleppo pine contributes to the livelihoods, food security, and improvement of the economy of the local population in rural areas of North Africa. It also provides an important economic safety net for the local population over a long period of the year (Taghouti et al. 2021). Hence, Aleppo pine has a high socio-economic value in such regions, where seed collection and timber harvest also provide employment for local workers. For all the above reasons, the reforestation of degraded areas in less developed countries should focus on Aleppo pine (Jaouadi et al. 2021). The protection of Aleppo pine forests is essential for combating desertification and providing local communities with essential services (Hezil et al. 2018).

The Aleppo pine forests in the Mediterranean zone are increasing in terms of area and biomass, and represent an important source of bioenergy as they offer an opportunity to mobilize woody matter, thereby contributing to the prevention and reduction of forest fires in the context of climate change and energy transition (Lerma-Arce et al. 2021).

The relationship between Aleppo pine and climatic factors is modulated by local conditions, especially the soil. Stable

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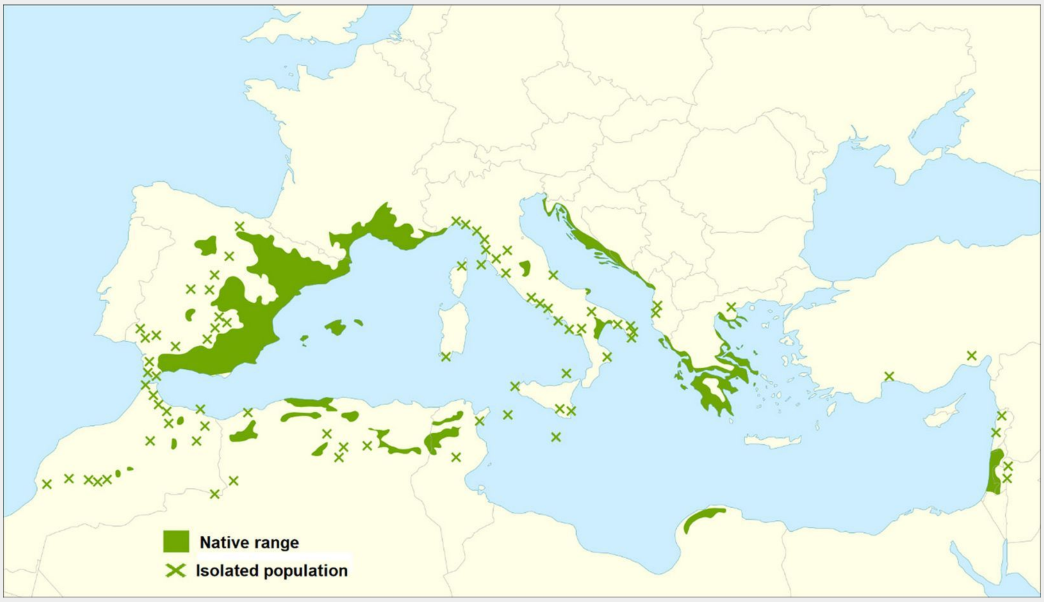

Fig. 1 - Natural range of *P. halepensis* (Caudullo et al. 2017).

stands are mostly located on sandstone substrates (Sarmoum et al. 2016). Tree-ring analysis has shown that exposure, altitude, and topographic position are determinants of pine growth (Guit & Nedjimi 2020). The wood of Aleppo pine has high dimensional stability and high compressive strength (Elaieb et al. 2017). For centuries, Aleppo pine forests have been subjected to strong human pressures (clearings, illegal cuttings, fires, and grazing), causing the regression of the vegetation cover. The maintenance of Aleppo pine stands subjected to continuous degradation for several decades is currently a major ecological issue (Guit & Nedjimi 2020).

In addition, in recent years, the Aleppo pine has been the main reforestation species used in degraded areas in several countries, owing to its plasticity and resistance to drought conditions; it is even able to colonize degraded and dry limestone soils. In adult stands with regular fruiting, the natural regeneration of Aleppo pine after wildfire passage is fairly common (Boudy 1952, Seigue 1985). Indeed, it has been noticed that after fire, Aleppo pine forests often undergo a massive regeneration, sometimes extending over large areas with a density of several tens of thousands of seedlings per hectare (Boudy 1950, Souleres 1969, Sari 1978). This phenomenon has been the subject of numerous studies in various regions of the Mediterranean Basin (Abbas et al. 1984, May 1987), which highlighted the rapid recolonization of burnt areas because of the great natural regeneration ability of pine. It also appears that natural regeneration is ensured by a large number of fertile seeds released from old (4 years and older), indehiscent cones known as "serotinous cones", which are ejected by the thermal shock caused by fire (Abbas et al. 1984).

The objective of this work was to review the production of Aleppo pine with regard to biomass, growth, and capacity for regeneration. Finally, we reviewed recent findings on the use of *P. halepensis* as rootstock in grafting operations and discuss its main advantages.

Materials and methods

Paper published between 1970 and 2021 were collected from Clarivate Web of Science®, Scopus®, and Science Direct®. The keywords used were "Aleppo pine stand", "biomass", "radial growth", "regeneration", "grafting", and "arid land". In addition, some doctoral thesis reports were consulted. The search results were refined based on the title and abstract of papers. After combining the relevant articles and all abstracts were scrutinized, the final database included 93 studies. The selected papers fulfilled the following criteria: (i) the study was published in English language; (ii) the scope of the study was biomass production in Aleppo pine stands.

Aboveground biomass of Aleppo pine forests

Smiris et al. (2000) showed that the determination of the biomass distribution in Aleppo pine stands is important for their effective management, and for planning conservation strategies and ecosystem valorisation as well. Allometric models help estimate biomass or volumes based on the dendrometric parameters of sample trees (López-Serrano et al. 2005, Ruiz-Peinado et al. 2011). In a study on *P. halepensis* biomass production in Mediterranean countries, Alfaro-Sánchez et al. (2015) reported that biomass production varies depending on local climate, stand age, and density of forest stands. Tree crowns represent the

Fig. 2 - Aleppo pine tree.

largest amount of biomass in Aleppo pine stands, followed by the root system and the stem biomass. Tab. 1 summarizes the biomass models used in Greece and Spain for Aleppo pine. According to Smiris et al. (2000), young (23-year-old) Aleppo pine stands have a productivity of 17.55 t ha^{-1} of biomass, which becomes 764.86 t ha^{-1} at the age of 48 years, 1192.24 t ha^{-1} at the age of 70 years, and finally 1406.21 t ha^{-1} at the age of 100 years. In this context, López-Serrano et al. (2005) showed that biomass production varies significantly with age and environmental conditions. The average residual biomass of a *P. halepensis* forest is 33.55 t ha^{-1}, but the standard deviation between plots has been estimated at 134.23 t ha^{-1} (Domingo et al. 2019). Furthermore, Alfaro-Sánchez et al. (2015) stated that climatic conditions are the main limiting factor for biomass production in Aleppo pine forests, showing that thinning practices play an important role in improving the biomass production of the stands. These evidences can help managers of forest ecosystems to assess the biomass, and determine the climatic and environmental factors influencing biomass production.

Radial growth of Aleppo pine

In recent decades, pine stands have been significantly affected by climate change worldwide (Andreu et al. 2007, Leal et al. 2008, Martin-Benito et al. 2010), showing dieback, tree mortality, and a decrease in growth owing to long, severe, and repeated droughts (Camarero et al. 2015). Camarero et al. (2020) studied the effects of climate change on 32 *P. halepensis* forests using a dendroclimatological approach and found that the growth of Aleppo pine significantly increased in the more humid sites. Notably, Aleppo pine exploits the water available in the soil during cool seasons, especially in winter and autumn, in the absence of other limiting environmental factors (Fotelli et al. 2019). These authors indicated that in the adult stage, Aleppo pine is very resistant and plastic in its response to adverse environmental conditions, and it is able to modulate the physiological activity according to environmental and seasonal conditions. Indeed, active growth has been recorded during spring and autumn, which are suitable seasons for growth of this species in the presence of favorable temperature and soil water availability (Fotelli et al. 2019). This behavior is more noticeable in coastal ecosystems than in continental ecosystems (Pacheco et al. 2018). On the other hand, Aleppo pine is resistant to drought and unfavorable environmental conditions, and it is able to recover from the effects of drought when environmental conditions improve. For example, Gazol et al. (2017) showed that Aleppo pine is able to uptake water from the soil during rainy seasons, thus presenting good growth performance in autumn and winter. This strategy allows Aleppo pine to successfully colonize nutrient-poor, abandoned, and dry lands (Chambel et al. 2013). These authors concluded that Aleppo pine can form stands resilient to drought while adding ecological value to the forest in terms of production and protection.

Novak et al. (2013a) studied intra-annual density fluctuations (IADF) in the rings of *P. halepensis*, finding that IADF formation occurs under favorable conditions in autumn, and it is not related to stressful summer conditions. Novak et al. (2013b) suggested that IADF formation reflects the plasticity of Aleppo pine and its ability to resume cambial activity after summer drought. Sarmoum et al. (2016) recorded a high variation in tree ring width among years even within the same stand. De Luis et al. (2011) noted that in the young stage, Aleppo pine show great plasticity in wood formation under the effect of drought. Additionally, Olivar et al. (2015) found that the radial growth of Aleppo pine was mainly influenced by rainfall. Similar results have been reported by Sarmoum et al. (2016). Camarero et al. (2020) studied the effect of environmental factors on the growth of *P. halepensis* stands and noted that their radial growth is related to the availability of water in the soil during previous wet seasons, namely previous spring and winter (Touchan et al. 2017, Choury et al. 2017). This result is similar to that of Olivar et al. (2015), who reported that the growth of *P. halepensis* is controlled by soil water availability throughout the year. In light of the above studies, Aleppo pine is a promising species to be used in reforestation in the Mediterranean areas which are characterized by a high variability in annual rainfall, and shows many advantages thanks to its plasticity and response to climatic conditions (Gutiérrez et al. 2011). Guit & Nedjimi (2020) showed that the physical environmental parameters have a significant effect on the growth of Aleppo pine, and the radial growth is an indicator of the performance of trees that are resistant to climate change. These positive relationships are explained by the high water requirement during the formation of tree rings (Papadopoulos et al. 2001). Olivar et al. (2015) showed that precipitation during spring and summer has a positive effect on the radial growth of Aleppo pine. These results corroborate those of Raventós et al. (2001) who found that, in the semi-arid climate of the Mediterranean zone, rainfall amount is the main factor that positively influences pine tree growth. Similarly, Bouachir et al. (2017) found that the amount of precipitation in winter and spring influenced the radial growth of Aleppo pine trees in Northern Africa. Other studies on tree-ring growth in Mediterranean regions have confirmed these results (Raventós et al. 2001, El Khorchani 2006, Campelo et al. 2007, Raddi et al. 2009, Mazza & Manetti 2013). Contrastingly, Battipaglia et al. (2014) reported that radial growth is significantly related to summer rainfall. Touchan et al. (2017) reported that the amount of precipitation in winter and spring have positive effects on the growth of the Aleppo pine. According to De Luis et al. (2013), the response functions of *P. halepensis* in the Mediterranean region revealed that temperature has a positive correlation with the tree-ring growth of Aleppo pine towards the northern limit of its geographical site and a negative correlation towards the southern limit. The results of Meko et al. (2020) were similar to those of Touchan et al. (2017) on the growth of Aleppo pine in the Mediterranean area, which showed that winter, spring, and summer precipitation positively influence the growth of the species, whereas species growth and summer temperature had a negative relationship (Touchan et al. 2017). The most significant radial growth for Aleppo pine was recorded in early spring (Choury et al. 2017), though it is not always present (Pacheco et al. 2018). Finally, Camarero et al. (2020) showed that radial growth in Aleppo pine is more pronounced at continental sites than at coastal sites.

Regeneration capacity of Aleppo pine

Aleppo pine is well known for the high seed productivity and the relevant regeneration ability (Nathan et al. 1999, Nathan & Neeman 2004), which is positively affected by humidity and temperature. Owing to its great regenerative ability, the Aleppo pine can colonize new sites over long distances (Lavi et al. 2005, Ledgard 1988, Buckley et al. 2004). Seed spread of Aleppo pine is largely favoured by wildlife in forests (De Villalobos et al. 2011, De Villalobos & Schwerdt 2020). The colonization of Aleppo pine causes changes in the colonized ecosystem such as an increase in biomass and changes in the physicochemical characteristics of the soil (Richardson & Higgins 1998). In North Africa, Aleppo pine has become an invasive species (Kalafat 2008). For example, in Algeria the frequent wildfires and the changing climate have favored the expansion of Aleppo pine into the oak ecosystem (Sarri 2017), where it can influence the physiological performance of the cork oak (Ghefar & Dehane 2018).

As already mentioned, the natural range of Aleppo pine extends to southern Europe, northern Africa, and some areas of the eastern Mediterranean (Barbéro et al. 1998, Quezel 2000), though the species is expanding in the Mediterranean area (Quezel 2000) and in several regions of its range Aleppo pine is considered an invasive species thanks to its ability to colonize different ecosystems (Nathan & Neeman 2004, Richardson 2000). Currently, Aleppo pine is rapidly colonizing oak ecosystems in many Mediterranean countries (Sheffer 2012). Osem et al. (2011) suggested that the expansion of Aleppo pine in Mediterranean areas could be favored by grazing, and Nuñez et al. (2017) showed that wild boars and deer are active dispersers of pine mycorrhizal symbionts. In France, the growth

Tab. 1 - Biomass models for *P. halepensis*.

Country	Parameters	Allometric relationships	Reference
Greece	Needles and small branches (d<0.5cm)	$W= exp^{(0.038+0.121d)}$	Smiris et al. (2000)
	Medium branches (0.5<d<2.5cm)	$W= exp^{(-0.826+0.124d)}$	
	Large branches (2.5<d<7.5cm)	$W= exp^{(-0.002+0.11\ d)}$	
	Stem wood with bark from live crown base to the top	$W= 174.495-15.099d+0.367d^2$	
	Stem wood with bark from stump to the live crown base	$W= -18.352+0.022(d^2h)$	
	Total tree, consisting of stem wood plus all branches	$W= -10.925+0.033(d^2h)$	
	Total branches	$W= exp(0.957+0.116\ d)$	
	Total stem wood with bark	$W= -30.74+0.027(d^2h)$	
	Crown, consisting of all branches plus topwood	$W= 16.942+0.006(d^2h)$	
	Needles	$W=exp(-0.521+0.121\ d)$	
	d diameter (cm) ; H height (m)		
Spain	H: total height (m)	$H= 2.554\ D^{0.45}$	López-Serrano et al. (2005)
	V: stem volume with bark (dm^3)	$V= 0.156\ D^{2.29}$	
	WS: drybiomass of tree stem (kg)	$WS= 0.088\ D^{2.25}$	
	WB: dry biomass of branches without needles (kg)	$WB= 0.017\ D^{2.53}$	
	WT: total dry biomass of tree (kg)	$WT= 0.128\ D^{2.29}$	
	WL: dry biomass of leaf (needles) (kg)	$WL= 0.026\ D^{1.93}$	
	L: leaf area (m^2)	$L= 0.173\ D^{1.80}$	
	Stem	$W_s= 0.0139\ d^2\ h$	Ruiz-Peinado et al. (2011)
	Thick branches	If d≤27.5 cm then Z = 0; If d > 27.5 cm then Z = 1; $W_{b7}= [3.926(d-27.5)]Z$	
	Medium branches	$W_{b2-7}= 4.257 + 0.00506d^2h - 0.0722dh$	
	Thin branches + needles	$W_{b2+n}= 6.197 + 0.00932d^2h - 0.0686dh$	
	Roots	$W_r= 0.0785d^2$	
	W_s: Biomass weight of the stem fraction (kg). W_{b7}: Biomass weight of the thick branch fraction (diameter larger than 7 cm) (kg). W_{b2-7}: Biomass weight of medium branch fraction (diameter between 2 and 7 cm) (kg). W_{b2+n}Biomass weight of thin branch fraction (diameter smaller than 2 cm) with needles (kg). W_r : Biomass weight of the belowground fraction (kg); d: dbh (cm). h: tree height (m).		
	b_{CW} = crown wood biomass	$\sqrt{b_{CW}}=8.78+0.96\cdot d^2$	Alfaro-Sánchez et al. (2015)
	b_N = needle biomass	$\sqrt{b_N}=9.43+0.83\cdot d^2$	
	b_C = crown biomass	$\sqrt{b_C}=12.93+1.27d^2$	
	b_{ST} = stem wood biomass	$\sqrt{b_{ST}}=7.19+0.89d^2$	
	b_{CO} = cone biomass	$b_{CO}=3.30+0.000284LD^2$	
	D : mean diameter at 30 cm above the ground (cm), D : individual width of female cones, L : individual length of female cones		

in the height of Aleppo pine notably accelerated between 1960 and 2000 (Vennetier et al. 1999). Bello-Rodríguez et al. (2020) reported that the expansion of Aleppo pine is very important to the island of La Gomera (Spain) and has increased since approximately 50 years, due to environmental conditions suitable to the species.

Several authors have confirmed the Aleppo pine expansion in many sites around the world where it has been introduced, including Australia, Brazil, Chile, Israel, New Zealand, South Africa, Uruguay, Venezuela, and the United States (Richardson & Higgins 1998, Richardson & Rejmánek 2004, Simberloff et al. 2010). Therefore, *Pinus halepensis* has become among the most important invasive pine species worldwide (Rejmánek & Richardson 1996, 2013, Richardson & Rejmánek 2011, Taylor et al. 2016), due to its great adaptability to different substrates and climates (Richardson 2000, Omary 2011, Girard et al. 2012, Vennetier et al. 2018). Lavi et al. (2005) reported that the invasion of Aleppo pine severely affect the local ecosystems by creating pine "islands" within the natural vegetation.

Use of Aleppo pine as rootstock for grafting

Grafting of pine trees for pine nut production allows to anticipate the start of production. This makes the investment more profitable and partially solves the problem of labor scarcity for the harvesting of cones, thanks to the lower height of grafted trees. Grafting stone pine onto Aleppo pine rootstocks broadens the range of use of the former species, thus promoting pine nut production in marginal areas (Sbay & Hajib 2016). Grafting stone pine grafts on Aleppo pine rootstocks has provided commendable results, especially because *P. halepensis* can adapt to degraded, dry, and nutrient-poor areas and grow on calcareous soils (Piqué et al. 2017). Indeed, plantations of *Pinus pinea* grafts on Aleppo pine rootstocks led to significant and earlier production of cones and nuts. These results can be exploited for the restoration and rehabilitation of rural areas to improve the standard of living of the local population while simultaneously improving the soil. Aletà & Vilanova (2014) showed that that using Aleppo pine as rootstock gave superior results compared to using stone pine rootstocks. The authors reported that using Aleppo pine rootstocks, the grafted plants were almost twice the height of trees grafted with stone pine rootstocks. Moreover, cone and seed production significantly improved, yielding 1.2 cones m^{-2} of canopy and 290 kg ha^{-1} using stone pine, compared with 4.8 cones m^{-2} and 376 kg ha^{-1} using Aleppo pine as rootstock. Grafted stone pine plantations in Spain and Tunisia showed high survival and promising growth rates, both with stone pine and Aleppo pine rootstocks, on many sites. Establishing stone pine fruit plantations requires grafting (Halett et al. 1981) with scions taken from selected subjects. This system is widely used in Spain, Portugal, and recently in Tunisia (Piqué et al. 2017) where stone pine has been grafted onto Aleppo pine. Grafting is usually carried out when rootstocks are 2-4 years old, with grafts taken from individuals selected for their cone production performances (Sbay & Hajib 2016). In Spain (Murcia and Castellon provinces), grafting was carried out on Aleppo pine rootstock, which is better adapted to on clay, marl, or gypsum soils than other pines. In the province of Castellon, more than 10,000 grafts of stone pine on Aleppo pine rootstocks have already been carried out; the oldest pines are now approximately 20-year-old (Sbay & Hajib 2016).

Conclusions

P. halepensis is an important tree of the Mediterranean region, characterised by high biomass productivity, and high plasticity with respect to climate and drought. Its radial growth varies with the environmental characteristics. The regeneration capacity of this species is notable and it is now considered an invasive species in different areas of the world. Moreover, the use of Aleppo pine as rootstock for stone pine nut production seems promising based on preliminary evidences. In light of this, Aleppo pine can be exploited as a promoter species in marginalized and degraded areas. This review can help forest managers developing optimal management strategies for Aleppo pine stands.

Conflicts of Interest

The authors declare no conflict of interest.

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References

Abbas H, Barbéro M, Loisel R (1984). Réflexion sur le dynamisme actuel de la régénération du pin d'Alep dans les pinèdes incendiées en Provence [Reflection on the current dynamism of Aleppo pine regeneration in burnt pinewoods in Provence]. Ecologia Mediterranea 10 (4): 85-104. [in French] - doi: 10.3406/ecmed.1984.1598

Aletà N, Vilanova A (2014). Cone production of stone pine grafted onto Aleppo pine. In: Proceedings of the "Medpine5 - 5th International Conference on Mediterranean Pines". Solsona (Spain) 2014. IRTA Institute of Agrifood Research and Technology, Spain, pp. 1.

Alfaro-Sánchez R, López-Serrano FR, Rubio E, Sánchez-Salguero R, Daniel Moya D, Hernández-Tecles E, De Las Heras J (2015). Response of biomass allocation patterns to thinning in *Pinus halepensis* differs under dry and semi arid Mediterranean climates. Annals of Forest Science 72: 595-607. - doi: 10.1007/s13595-015-0480-y

Andreu L, Gutierrez E, Macias M, Ribas M, Bosch O, Camarero JJ (2007). Climate increases regional tree-growth variability in Iberian pine forests. Global Change Biology 13: 1-12. - doi: 10.1111/j.1365-2486.2007.01322.x

Barbéro M, Loisel R, Quezel P, Richardson DM, Romane F (1998). Pines of the Mediterranean Basin. Ecology and Biogeography of *Pinus*. Cambridge University Press, Cambridge, UK, pp. 153-170.

Battipaglia G, Strumia S, Esposito A, Giuditta E, Sirignano C, Altieri S, Rutigliano FA (2014). The effects of prescribed burning on *Pinus halepensis* Mill. as revealed by dendrochronological and isotopic analyses. Forest Ecology and Management 334: 201-208. - doi: 10.1016/j.foreco.2014.09.010

Bello-Rodríguez V, Cubas J, Fernández AB, Aguilar MJDA, González-Mancebo JM (2020). Expansion dynamics of introduced *Pinus halepensis* Miller plantations in an oceanic island (La Gomera, Canary Islands). Forest Ecology and Management 474: 118-128. - doi: 10.1016/j.foreco.2020.118374

Bentouati A, Oudjehih B, Alatou D (2005). Croissance en hauteur dominante et classes de fertilité du pin d'Alep (*Pinus halepensis* Mill.) dans le massif de Ouled Yakoub et des Beni Oudjana (Khenchela-Aures) [Dominant height growth and fertility classes of Aleppo pine (*Pinus halepensis* Mill.) in the massif of Ouled Yakoub and Beni Oudjana (Khenchela-Aures)]. Sciences and Technologie 23: 57-62. [in French] [online] URL: http://revue.umc.edu.dz/index.php/c/article/view/1379

Bouachir BB, Khorchani A, Guibal F, El Aouni MH, Khaldi A (2017). Dendroecological study of *Pinus halepensis* and *Pinus pinea* in northeast coastal dunes in Tunisia according to distance from the shoreline and dieback intensity. Dendrochronologia 45: 62-72. - doi: 10.1016/j.dendro.2017.06.008

Boudy P (1950). Economie forestière nord-africaine. II. Monographies et traitement des essences forestières [North African forestry economy. II. Monographs and treatment of forest species]. La Rose, Paris, France, pp. 887. [in French]

Boudy P (1952). Guide du forestier en Afrique du nord [Guide for foresters in North Africa]. Ed. Maison Rustique, Paris, France, pp. 505. [in French]

Buckley YM, Rees M, Paynter Q, Lonsdale WM (2004). Modelling integrated weed management of an invasive shrub in tropical Australia. Journal of Applied Ecology 41 (3): 547-560. - doi: 10.1111/j.0021-8901.2004.00909.x

Camarero JJ, Gazol A, Sangüesa-Barreda G, Oliva J, Vicente-Serrano SM (2015). To die or not to die: early warnings of tree dieback in response to a severe drought. Journal of Ecology 103 (1): 44-57. - doi: 10.1111/1365-2745.12295

Camarero JJ, Sánchez-Salguero R, Ribas M, Touchan R, Andreu-Hayles L, Dorado-Liñán I, Meko DM, Gutiérrez E (2020). Biogeographic, atmospheric, and climatic factors influencing tree growth in Mediterranean Aleppo pine forests. Forests 11: 736. - doi: 10.3390/f11070736

Campelo F, Nabais C, Freitas H, Gutiérrez E (2007). Climatic significance of tree-ring width and intra-annual density fluctuations in *Pinus pinea* from a dry Mediterranean area in Portugal. Annals of Forest Science 64 (2): 229-238. - doi: 10.1051/forest:2006107

Caudullo G, Welk E, San-Miguel-Ayanz J (2017). Chorological maps for the main European woody species. Data in Brief 12: 662-666. - doi: 10.1016/j.dib.2017.05.007

Chambel MR, Climent J, Pichot C, Ducci F (2013). Mediterranean pines (*Pinus halepensis* Mill. and *P. brutia* Ten.). In: "Forest Tree Breeding in Europe" (Paques L ed). Managing Forest Ecosystems, vol 25, Springer, Dordrecht, Netherlands, pp. 229-265.

Choury Z, Shestakova TA, Himrane H, Touchan R, Kerchouche D, Camarero JJ, Voltas J (2017). Quarantining the Sahara desert: growth and water-use eciency of Aleppo pine in the Algerian Green Barrier. European Journal of Forest Research 136: 139-152. - doi: 10.1007/s10342-016-1014-3

Couhert B, Duplat P (1993). Le pin d'Alep. Rencontres forestiers-chercheurs en forêt méditerranéenne [Aleppo pine. Meetings between foresters and researchers in Mediterranean forests]. La Grande Iviotte (34), 6-7 Oct 1993. INRA, Paris, France. Les colloques 63: 125-147. [in French]

De Luis M, Cufar K, Di Filippo A, Novak K, Papadopoulos A, Piovesan G, Rathgeber CBK, Raventós J, Saz MA, Smith KT (2013). Plasticity in dendroclimatic response across the distribution range of Aleppo pine (*Pinus halepensis*). PLoS One 8 (12): e83550. - doi: 10.1371/journal.pone.0083550

De Luis M, Novak K, Raventós J, Gričar J, Prislan P, Cufar K (2011). Cambial activity, wood formation and sapling survival of *Pinus halepensis* exposed to different irrigation regimes. Forest Ecology and Management 262: 1630-1638. - doi: 10.1016/j.foreco.2011.07.013

De Villalobos AE, Schwerdt L (2020). Seasonality of feral horse grazing and invasion of *Pinus halepensis* in grasslands of the Austral Pampean Mountains (Argentina): management considerations. Biological Invasions 22 (10): 2941-2955. - doi: 10.1007/s10530-020-02300-x

De Villalobos AE, Zalba SM, Peláez DV (2011). Pinus halepensis invasion in mountain pampean grassland: effects of feral horses grazing on seedling establishment. Environmental Research 111 (7): 953-959. - doi: 10.1016/j.envres.2011.03.011

DGF (2010). Inventaire National Forestier de la Tunisie [National Forestry Inventory of Tunisia]. Inventaire des forêts par télédétection. Résultats du deuxième inventaire forestier et pastoral national, Direction Générale des Forêts, Tunisia, pp. 88. [in French]

Domingo D, Luis Montealegre A, Teresa Lamelas M, García-Martín A, De la Riva J, Rodríguez F, Alonso R (2019). Quantifying forest residual biomass in *Pinus halepensis* Miller. stands using Airborne Laser Scanning data. GIScience and Remote Sensing 56 (8): 1210-1232. - doi: 10.1080/15481603.2019.1641653

El Khorchani A (2006). Approche dendrochronologique de l'influence des changements climatiques sur la productivité des forêts de pin d'Alep (*Pinus halepensis* Mill.) en Tunisie [A dendrochronological approach to the influence of climate change on the productivity of Aleppo pine (*Pinus halepensis* Mill.) forests in Tunisia]. PhD thesis, Université Paul Cézanne, Aix-Marseille, France, pp. 211. [in French]

Elaieb MT, Shel F, Elouellani S, Janah T, Rahouti M, Thévenon MF, Candelier K (2017). Physical, mechanical and natural durability properties of wood from reforestation *Pinus halepensis* Mill. in the Mediterranean Basin. Bois et Forêts des Tropiques 1 (331): 19-31. - doi: 10.19182/bft2017.331.a31323

Fotelli MN, Korakaki E, Paparrizos SA, Radoglou R, Awada T, Matzarakis A (2019). Environmental controls on the seasonal variation in gas exchange and water balance in a near-coastal Mediterranean *Pinus halepensis* forest. Forests 10 (4): 313. - doi: 10.3390/f10040313

Gazol A, Ribas M, Gutierrez E, Camarero JJ (2017). Aleppo pine forests from across Spain show drought-induced growth decline and partial recovery. Agricultural and Forest Meteorology 232: 186-194. - doi: 10.1016/j.agrformet.2016.08.014

Ghefar M, Dehane B (2018). Etude des paramètres réglant la production du liège dans la subéraie de M'Sila (Oran, Algérie). [Study of the parameters regulating the production of cork in the M'Sila cork grove (Oran, Algeria)]. Agriculture and Forestry Journal 2 (1): 48-58. [in French] [online] URL: http://ojs.univ-tlemcen.dz/index.php/AFJ

Girard F, Vennetier M, Guibal F, Corona C, Ouarmim S, Herrero A (2012). *Pinus halepensis* Mill. crown development and fruiting declined with repeated drought in Mediterranean France. European Journal of Forest Research 131: 919-931. - doi: 10.1007/s10342-011-0565-6

Guit B, Nedjimi B (2020). Croissance radiale du pin d'Alep (*Pinus halepensis* Mill.) en fonction des paramètres stationnels dans les massifs forestiers naturels de l'Atlas saharien algérien. [Radial growth of Aleppo pine (*Pinus halepensis* Mill.) as a function of site parameters in the natural forest massifs of the Algerian Saharan Atlas]. Bois et Forêts des Tropiques 345: 3-11. [in French] - doi: 10.19182/bft2020.345.a31803

Gutiérrez E, Campelo F, Camarero JJ, Ribas M, Muntán E, Nabais C, Freitas H (2011). Climate controls act at different scales on the seasonal pattern of *Quercus ilex* L. stem radial increments in NE Spain. Trees, Structure and Function 25: 637-646. - doi: 10.1007/s00468-011-0540-3

Hallett RD, Smith RF, Burns TW (1981). Manual for greenhouse grafting of conifers in the Maritimes. Information Report M-X-117, Environment Canada, Canadian Forestry Service, Maritimes Forest Research Centre, Fredericton, New Brunswick, Canada, pp. 21.

Hezil S, Chakali G, Battisti A (2018). Plant phenotype affects oviposition behaviour of pine processionary moth and egg survival at the southern edge of its range. iForest 11: 572-576. - doi: 10.3832/ifor2675-011

Jaouadi W, Mechergui K, Khouja M, Khouja ML (2021). Potential of Aleppo pine production in north-eastern Tunisia: socio-economic value and cultural importance. International Journal of Environmental Studies 78 (3): 491-503. - doi: 10.1080/00207233.2020.1824882

Jaouadi W, Naghmouchi S, Alsubeie M (2019). Should the silviculture of Aleppo pine (*Pinus halepensis* Mill.) stands in northern Africa be oriented towards wood or seed and cone production? Diagnosis and current potentiality. iForest 12: 297-305. - doi: 10.3832/ifor2965-012

Kadik B (1987). Contribution à l'étude du pin d'Alep (*Pinus halepensis* Mill.) en Algérie. Écologie, dendrométrie, morphologie [Contribution to the study of Aleppo pine (*Pinus halepensis* Mill.) in Algeria. Ecology, dendrometry, morphology]. Office des Publications Universitaires, Algiers, Algéria, pp. 580. [in French]

Kalafat D (2008). La dynamique de la végétation dans la région d'Oran: cas du Djebel Murdjadjo. [Vegetation dynamics in the Oran region: case of Jebel Murdjadjo]. Rapport Magister, Faculté des Sciences, Université d'Oran, Algérie, pp. 106. [in French]

Lavi A, Perevolotsky A, Kigel J, Noy-Meir I (2005). Invasion of *Pinus halepensis* from plantations into adjacent natural habitats. Applied Vegetation Science 8 (1): 85-92. - doi: 10.1111/j.1654-109X.2005.tb00632.x

Leal S, Emaus D, Grabner M, Wimmer R, Cherubini P (2008). Tree rings of Pinus nigra from the Vienna basin region (Austria) show evidence of change in climatic sensitivity in the late 20th century. Canadian Journal of Forest Research 38: 744-759. - doi: 10.1139/X07-189

Ledgard NJ (1988). The spread of introduced trees in New Zealand's rangelands - South Island high country experience. Journal of the Tussock Grasslands and Mountain Lands Institute 44: 1-8.

Lerma-Arce V, Oliver-Villanueva JV, Segura-Orenga G, Urchueguia-Schölzel JF (2021). Comparison of alternative harvesting systems for selective thinning in a Mediterranean pine afforestation (*Pinus halepensis* Mill.) for bioenergy use. iForest 14: 465-472. - doi: 10.3832/ifor3636-014

López-Serrano FR, García-Morote A, Andrés-Abellán M, Tendero A, Del Cerro A (2005). Site and weather effects in allometries: a simple approach to climate change effect on pines. Forest Ecology and Management 215 (1-3): 251-270. - doi: 10.1016/j.foreco.2005.05.014

Martin-Benito D, Del Rio M, Cañellas I (2010). Black pine (*Pinus nigra* Arn.) growth divergence along a latitudinal gradient in Western Mediterranean Mountains. Annals of Forest Science 67 (4): 401-401. - doi: 10.1051/forest/2009121

May T (1987). L'état de la végétation 9 ans après l'incendie d'un reboisement de *Pinus halepensis* en Andalousie orientale [The state of the vegetation 9 years after the fire in a *Pinus halepensis* reforestation in eastern Andalusia]. Forêt Méditerranéenne 9 (2): 139-142. [in French]

Mazza G, Manetti MC (2013). Growth rate and climate responses of *Pinus pinea* L. in Italian coastal stands over the last century. Climatic Change 121 (4): 713-725. - doi: 10.1007/s10584-013-0933-y

Meko DM, Touchan R, Kherchouche D, Slimani S (2020). Direct *versus* indirect tree ring reconstruction of annual discharge of Chemora River, Algeria. Forests 11 (9): 986. - doi: 10.3390/f11090986

Minervini F, Missaoui J, Celano G, Calasso M, Achour L, Saidane D, Gobbetti M, De Angelis M (2020). Use of autochthonous Lactobacilli to increase the safety of Zgougou. Microorganisms 8 (1): 29. - doi: 10.3390/microorganisms8010029

Montero G, Cañellas I, Ruiz-Peinado D (2001). Growth and yield model for *Pinus halepensis* Mill. Forest Systems 10 (1): 179-201. [online] URL: http://sia.revistas.inia.es/index.php/fs/article/view/720

Nathan R, Neeman G (2004). Spatiotemporal dynamics of recruitment in Aleppo pine (*Pinus halepensis* Miller). Plant Ecology 171 (1-2): 123-137. - doi: 10.1023/b:vege.0000029379.32705.0f

Nathan R, Safriel UN, Noy-Meir I, Schiller G (1999). Seed release without fire in *Pinus halepensis*, a Mediterranean serotinous wind-dispersed tree. Journal of Ecology 87 (4): 659-669. - doi: 10.1046/j.1365-2745.1999.00382.x

Neeman G, Trabaud L (2000). Ecology, biogeography and management of *Pinus halepensis* and *P. brutia* forest ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, Netherlands, pp. 407. - doi: 10.1046/j.0022-0477.2001.00591.x

Novak K, Cufar K, De Luis M, Sánchez MAS, Raventós J (2013b). Age, climate and intra-annual density fluctuations in *Pinus halepensis* in Spain. IAWA Journal 34: 459-474. - doi: 10.1163/22941932-00000037

Novak K, De Luis M, Raventós J, Cufar K (2013a). Climatic signals in tree-ring widths and wood structure of *Pinus halepensis* in contrasted environmental conditions. Trees 27: 927-936. - doi: 10.1007/s00468-013-0845-5

Nuñez MA, Chiuffo MC, Torres A, Paul T, Dimarco RD, Raal P, Policelli N, Moyano J, Garcia RA, Van Wilgen VW, Pauchard A, Richardson DM (2017). Ecology and management of invasive Pinaceae around the world: progress and challenges. Biological Invasions 19: 3099-3120. - doi: 10.1007/s10530-017-1483-4

Olivar J, Bogino S, Spiecker H, Bravo F (2015). Changes in climate-growth relationships and IADF formation over time of pine species (*Pinus halepensis, P. pinaster* and *P. sylvestris*) in Mediterranean environments. Forest Systems 24 (1): 2171-9845. - doi: 10.5424/fs/2015241-05885

Omary AA (2011). Effects of aspect and slope position on growth and nutritional status of planted Aleppo pine (*Pinus halepensis* Mill.) in a degraded land semi-arid areas of Jordan. New Forest 42: 285-300. - doi: 10.1007/s11056-011-9251-2

Osem Y, Lavi A, Rosenfeld A (2011). Colonization of *Pinus halepensis* in Mediterranean habitats: consequences of afforestation, grazing and fire. Biological Invasions 13: 485-498. - doi: 10.1007/s10530-010-9843-3

Pacheco A, Camarero JJ, Ribas M, Gazol A, Gutiérrez E, Carrer M (2018). Disentangling the climate-driven bimodal growth pattern in coastal and continental Mediterranean pine stands. Science of the Total Environment 615: 1518-1526. - doi: 10.1016/j.scitotenv.2017.09.133

Papadopoulos A, Serre-Bachet F, Tessier L (2001). Tree ring to climate relationships of Aleppo pine (*Pinus halepensis* Mill.) in Greece. Ecologia Mediterranea 27 (1): 89-98. - doi: 10.3406/ecmed.2001.1908

Piqué M, Coello J, Ammari Y, Aleta A, Sghaeir T, Mutke S (2017). Grafted stone pine plantations for cone production: traits on *Pinus pinea* and *Pinus halepensis* rootstocks from Tunisia and Spain. Options Méditerrannénnens 122: 17-23.

Quezel P (1980). Biogéographie et écologie des conifères sur le pourtour méditerranéen. Actualités d'écologie forestière [Biogeography and ecology of conifers in the Mediterranean region. News on forest ecology]. Edition Gautier-Villars, Paris, France, pp. 205-255. [in French]

Quezel P (2000). Taxonomy and biogeography of Mediterranean pines (*Pinus halepensis* and *P. brutia*). In: "Ecology, Biogeography and Management of *Pinus halepensis* and *Pinus brutia* Forest Ecosystems in the Mediterranean Basin" (Ne'eman G, Trabaud L eds). Backhuys, Leiden, Netherlands, pp. 1-12.

Quezel P, Barber M (1992). Le Pin d'Alep et les essences voisines: répartition et caractères écologiques généraux, sa dynamique récente en France Méditerranéenne [Aleppo pine and related species: Distribution and general ecological characteristics, its recent dynamics in Mediterranean France]. Forêt Méditerranéenne 13 (3): 158-170. [in French]

Raddi S, Cherubini P, Lauteri M, Magnani F (2009). The impact of sea erosion on coastal *Pinus pinea* stands: a diachronic analysis combining tree-rings and ecological markers. Forest Ecology and Management 257: 773-781. - doi: 10.1016/j.foreco.2008.09.025

Raventós J, De Luis M, Gras M, Cufar K, González-Hidalgo J, Bonet A, Sánchez J (2001). Growth of *Pinus pinea* and *Pinus halepensis* as affected by dryness, marine spray and land use changes in a Mediterranean semiarid ecosystem. Dendrochronologia 19: 211-220.

Rejmánek M, Richardson DM (1996). What attributes make some plant species more invasive? Ecology 77: 1655-1661. - doi: 10.2307/2265768

Rejmánek M, Richardson DM (2013). Trees and shrubs as invasive alien species - 2013 update of the global database. Diversity and Distributions 19: 1093-1094. - doi: 10.1111/ddi.12075

Richardson DM (2000). Mediterranean pines as invaders in the southern hemisphere. In: "Ecology, Biogeography and Management of *Pinus halepensis* and *Pinus brutia* Forest Ecosystems in the Mediterranean Basin" (Neeman G, Trabaud L eds). Backhuys Publishers, Leiden, Netherlands, pp. 131-142.

Richardson DM, Higgins SI (1998). Pines as invaders in the Southern Hemisphere. In: "Ecology and Biogeography of *Pinus*" (Richardson DM ed). Cambridge University Press, Cambridge, UK, pp. 450-473.

Richardson DM, Rejmánek M (2004). Conifers as invasive aliens: a global survey and predictive framework. Diversity and Distributions 10(5-6): 321-331. - doi: 10.1111/j.1366-9516.2004.00096.x

Richardson DM, Rejmánek M (2011). Trees and shrubs as invasive alien species - a global review. Diversity and Distributions 17 (5): 788-809. - doi: 10.1111/j.1472-4642.2011.00782.x

Ruiz-Peinado R, Del Rio M, Montero G (2011). New models for estimating the carbon sink capacity of Spanish softwood species. Forest Systems 20 (1): 176-188. - doi: 10.5424/fs/2011201-11643

Sari D (1978). Le reboisement de l'Ouarsenis. Recherches sur l'Algérie [The reforestation of the Ouarsenis. Research on Algeria]. Mémoires et Documents 17: 101-164. [in French]

Sarmoum M, Guibal F, Abdoun F (2016). Effet des facteurs stationnels sur la croissance radiale et la réponse du pin d'Alep au climat dans le massif de l'Ouarsenis, Algérie [Effect of site factors on radial growth and response of Aleppo pine to climate in the Ouarsenis massif, Algeria]. Bois et Forêts des Tropiques 329 (3): 17-27. [in French] - doi: 10.19182/bft2016.329.a31308

Sarri D (2017). Développement durable au sein des aires protégées algériennes, cas du parc national d'El Kala et des sites d'intérêts biologiques et écologiques de la région d'El Taref [Sustainable development within Algerian protected areas, case of El Kala national park and sites of biological and ecological interest in the region of El Taref]. PhD thesis, Université Farhat-Abbas Sétif 1, Faculté des Sciences de la Nature et de la Vie, Algérie, pp. 240. [In French]

Sbay H, Hajib S (2016). Le pin pignon: une espèce de choix dans le contexte des changements climatiques. [Stone pine: a species of choice in the context of climate change]. Centre de Recherches Forestières, Maroc, pp. 76. [in French]

Segura C, Fernández-Ondoño E, Jiménez MN, Navarro FB (2019). Carbon and nutrient contents in the miscellaneous fraction of litterfall under different thinning intensities in a semiarid *Pinus halepensis* afforestation. iForest 12: 375-382. - doi: 10.3832/ifor2907-012

Seigue A (1985). La forêt circum méditerranéenne et ses problèmes [The circum-Mediterranean forest and its problems]. Maison Neuve et La Rose, Paris, France, pp. 502. [in French]

Sheffer E (2012). A review of the development of Mediterranean pine-oak ecosystems after land abandonment and afforestation: are they novel ecosystems? Annals of Forest Science 69: 429-443. - doi: 10.1007/s13595-011-0181-0

Simberloff D, NunezMA, Ledgard NJ, Pauchard A, Richardson DM, Sarasola M, Van Wilgen BW, Zalba SM, Zenni RD, Bustamante R, Pena E, Ziller SR (2010). Spread and impact of introduced conifers in South America: lessons from other southern hemisphere regions. Austral Ecology 35: 489-504. - doi: 10.1111/j.1442-9993.2009.02058.x

Smiris P, Maris F, Vitoris K, Stamou N, Kalambokidis K (2000). Aboveground biomass of *Pinus halepensis* Mill. forests in the Kassandra Peninsula - Chalkidiki. Silva Gandavensis 65: 173-187. - doi: 10.21825/sg.v65i0.815

Souleres G (1969). Le pin d'Alep en Tunisie [Aleppo pine in Tunisia]. Annales de l'Institut National de Recherches Forestières, Tunisia, pp. 126. [in French]

Taghouti I, Ouertani E, Guesmi B (2021). The contribution of non-wood forest products to rural livelihoods in Tunisia: the case of Aleppo pine. Forests 12 (12): 1793. - doi: 10.3390/f12121793

Taylor KT, Maxwell BD, Pauchard A, Nuñez MA, Peltzer DA, Terwei A, Rew LJ (2016). Drivers of plant invasion vary globall: evidence from pine invasions within six ecoregions. Global Ecology and Biogeography 25: 96-106. - doi: 10.1111/geb.12391

Touchan R, Anchukaitis KJ, Meko DM, Kerchouche D, Slimani S, Ilmen R, Hasnaoui F, Guibal F, Camarero JJ, Sánchez-Salguero R, Piermattei A, Sesbou A, Cook I, Sabir M, Touchane H (2017). Climate controls on tree growth in the Western Mediterranean. The Holocene 27 (10): 1429-1442. - doi: 10.1177/0959683617693901

Vennetier M, Ripert C, Brochiero F, Chandioux O (1999). Evolution à court et long terme de la croissance du pin d'Alep en Provence. Conséquence sur la production de bois. [Short- and long-term evolution of the growth of the Aleppo pine in Provence. Consequence on wood production]. Forêt Méditerranéenne 20 (4): 147-156. [in French]

Vennetier M, Ripert C, Rathgeber C (2018). Autecology and growth of Aleppo pine (*Pinus halepensis* Mill.): a comprehensive study in France. Forest Ecology and Management 413: 32-47. - doi: 10.1016/j.foreco.2018.01.028

