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# Relationship between climate and growth of two North African varieties of *Pinus pinaster* Arn.

**Sondes Fkiri**[1,2] | **Frédéric Guibal**[3] | **Ali El Khorchani**[1] | **M. Larbi Khouja**[1] | **Abdelhamid Khaldi**[1] | **Zouhair Nasr**[1]

[1]National Research Institute of Rural Engineering, Water and Forestry (INRGREF), Ariana-, Tunisia

[2]National Institute of Agronomy, Tunis-, Tunisia

[3]IMBE, Institut Méditerranéen de Biodiversité et d'Ecologie, Aix Marseille Universite, Avignon Université, CNRS, IRD Europôle Méditerranéen de l'Arbois, Aix en Provence Cedex 4, France

**Correspondence**
Sondes Fkiri, National Research Institute of Rural Engineering, Water and Forestry (INRGREF), Ariana, Tunisia.
Email: sondesfkiri@gmail.com

## Abstract

Planting tree species that are well adapted to local ecological conditions guarantees the success and sustainability of forest restoration. The aim of this study was to investigate the acclimation of two varieties of *Pinus pinaster* (var. *renoui* from Tunisia and var. *maghrebiana* from Morocco), to the ecological conditions of the Kroumirie Mountains in northwest of Tunisia. Tree growth performance (diameter at 1.30 m [DBH], ring widths and total height) and climate–growth responses over the period 1970–2013 were evaluated for two varieties. The trees used in this study were from pine variety and provenance trials growing in common garden in Souiniet (21 trees per variety). Significant difference in height growth rate, DBH and ring widths was found between the two varieties. The Maghrebiana variety had the highest survival and mean radial growth rates. The mean sensitivity to climate was the same in two varieties. A significant negative correlation between May precipitation and radial growth was found for var. *maghrebiana*. Both varieties showed a significant negative correlation between May and June temperatures and radial growth. January–February temperatures had a positive influence on ring width. The Maghrebiana variety appears well acclimatised so it is expected to ensure more successful restoration of Kroumirie Mountains.

## Résumé

Planter des essences bien adaptées aux conditions écologiques locales garantit le succès et la durabilité de la restauration des forêts. L'objectif de cette étude était d'évaluer l'acclimatation de deux variétés de Pinus pinaster (var. Renoui de la Tunisie et var. Maghrebiana du Maroc) aux conditions écologiques des montagnes de la Kroumirie au nord-ouest de la Tunisie. Les performances de croissance des arbres (diamètre à 1,30 m [DBH], largeurs de cernes et hauteur totale) et les réponses climatcroissance sur la période 1970-2013 ont été évaluées pour les deux variétés. Les arbres utilisés dans cette étude provenaient d'essais de variétés et des provenances de pins poussant dans une plantation comparative à Souiniet (21 arbres par variété). Une différence significative entre les taux de croissance en hauteur, en DBH et des largeurs des cernes a été observée entre les deux variétés. La variété Maghrebiana avait les taux de survie et de croissance radiale les plus élevés. La sensibilité moyenne au climat était la même dans les deux variétés. Une corrélation négative significative entre les précipitations de mai et la croissance radiale a été enregistrée pour maghrebiana var. Les deux variétés ont montré une correlation négative significative entre les températures de mai-juin et la croissance radiale. Les températures de janvier-février ont eu une influence positive sur la largeur des cernes. La variété Maghrebiana semble bien acclimatée donc, il est prévu d'assurer une restauration plus réussie des montagnes de la Kroumirie.

**KEYWORDS**
acclimation, dendroecology, Kroumirie Mountains, maritime pine, restoration

## 1 | INTRODUCTION

Several adaptive forest management strategies that may require changes in forestry guidelines have been recommended for the sustainable use of multifunctional Mediterranean forests to enhance long-term carbon storage and further mitigate climate change (Regato, 2008; Vericat, Pique, & Serrada, 2012). In response to the widespread forest degradation in Mediterranean region, restoration is increasingly being implemented in many Mediterranean areas (Mercurio, 2010). The capacity of selected species to adapt and acclimate to expected temperature increases that various parts of North Africa have experienced over the last 30 years raises questions (Touchan et al., 2011). Changes in precipitation patterns and the frequency and duration of drought are likely to be more frequent. It is also expected that extreme events will become more frequent and intense (IPCC, 2013). Combined with periods of more severe drought, warming could increase the frequency of fire, which may hinder the regeneration of species and accelerate the desertification. Such changes could also increase the risk of extinction of a wide range of species and ecosystems.

In Tunisia, many reforestation programmes for soil and water conservation have been established (Aloui, 1987; Khouja & Najjar, 1989). Planted forests now account for more than 50% of the forest estates in Tunisia (FAO & Plan Bleu, 2013).

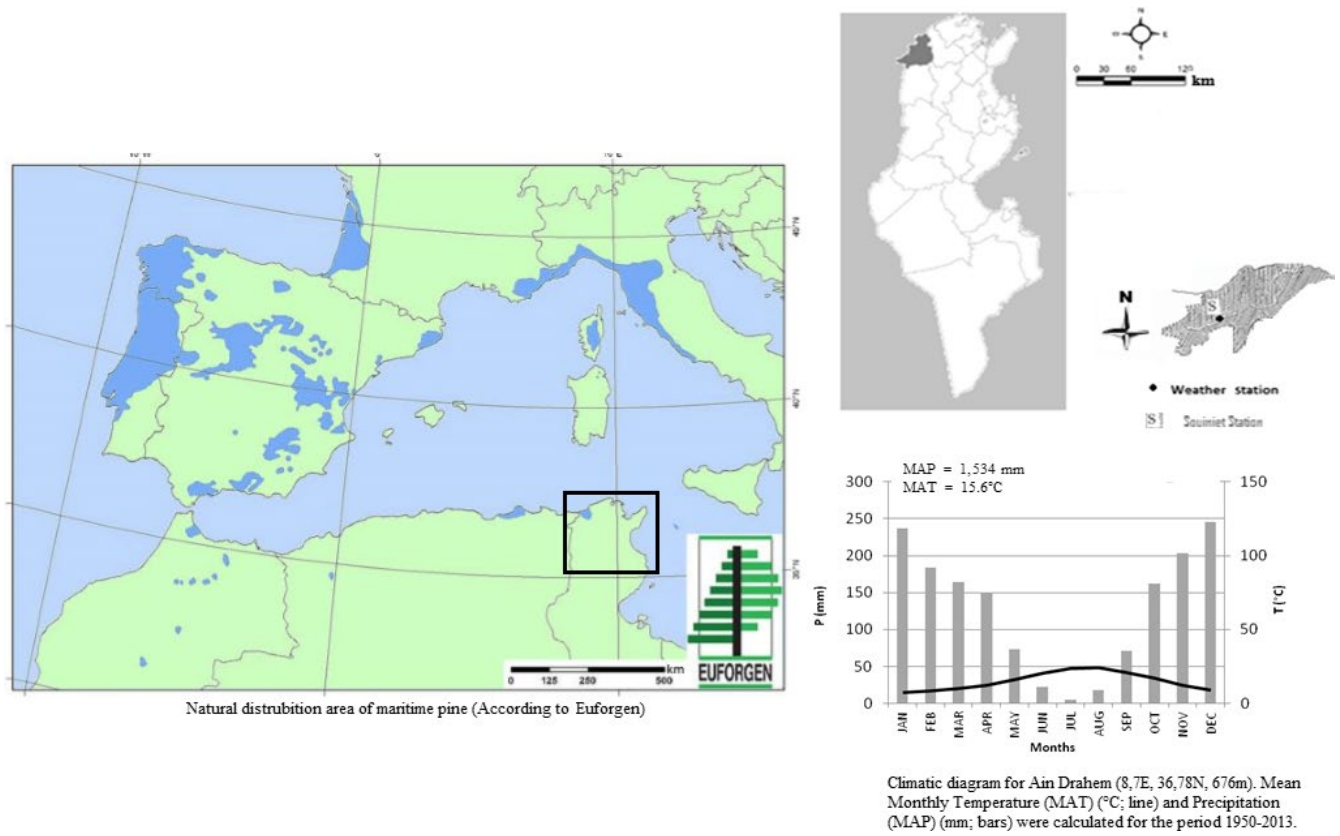


**FIGURE 1** Location of study site (36°48′N, 8°48′E, 492 m). The experimental dispositive is located at Souiniet site in Ain Drahem province under humid Mediterranean bioclimate (northwest of Tunisia)

In 1964, General Direction of Forestry (DGF) conducted provenance trials (planting experiments aimed at understanding how trees are adapted to different environmental conditions through genetic adaptation or phenotypic plasticity) for different pine species (*Pinus*) such as *halepensis*, *pinea*, *pinaster*, *brutia*, *canariensis*, *radiata and nigra* to identify those that are best adapted to ecological conditions of Tunisia (Khouja et al., 2004).

Net primary productivity is a widely used indicator of tree growth performance that can be an important element of forestry management (Rondeux, 1977). Tree growth response is fundamental to understanding the ecology of species and forest ecosystems and predicting future ecosystem services (Rapp et al., 2012). Tree growth is limited by climate; tree rings are a proxy for climatic conditions. In fact, tree-ring dating (or dendrochronology) is a powerful tool to understand the effects of specific environmental factors on tree growth, such as climate, by analysing inter-annual variations in ring-width series (Schweingruber, 1996; Sheppard, 2010). The ring width shows the amount of radial growth that occurred in 1 year and thus indicates the growing conditions for that year. When the conditions are favourable, tree grows faster and so lays down more ligneous tissue during the year, resulting in wider tree rings. Bad conditions mean slower growth, less ligneous tissue laid down and consequently a narrower tree ring (Lebourgeois & Mérian, 2012). Although several studies have been set up to study the productivity of reforestation pines in Tunisia (Aloui, 1987; Aloui, 2006; Khouja, 2003; Khouja et al., 2004; Khouja & Najjar, 1989; Khouja et al. 2006), very few of them have addressed the issue of growth response to climate, in areas where the climate is expected to change significantly and aggravate growth conditions (Aloui, 1987; El Khorchani, Gadbin-Henry, Bouzid, & Khaldi, 2007).

The maritime pine (*P. pinaster* Arn.) is a conifer of the western Mediterranean Basin with a distribution exceeding 4 million hectares under broad ranges of elevation, climate and soil. It is mainly a pine of low-lying, coastal plains, usually growing on sandy soils of seashore dunes and flats; however, in Morocco, this species extends into the mountains to an altitude of approximately 2,000 m (Quézel & Médail, 2003). The species is sensitive to frost, which probably explains why it climbs to the mountains only in the far south of its range.

Programmes motivated by soil protection and reforestation of degraded areas extended the maritime pine in the 19th and 20th centuries (Le Maitre, 1998). Extensive planting, for example in sand dunes, for centuries has set this species in areas where it may not have occurred naturally. Species can grow on a variety of substrates and under several Mediterranean climate regimes, ranging from semi-arid to humid. In North Africa, maritime pine plays a key role in reforestation because of its fast and vigorous growth, occupying 28,000 ha (Boudy, 1952; Praciak et al., 2013) (Figure 1). It is located in the Algerian–Tunisian coast, from Bejaia to Tabarka. It represents 68% of the national forest area of Tunisia (DGF, 1995). In Morocco, this species represents approximately 90% of the coniferous plantations of the Rif Mountain (North of Morocco) and the eastern Middle Atlas (Belghazi & Ezzahir, 1995).

In order to provide more effective assistance to foresters for current and future pine afforestation, efforts are concentrated on finding for a range of pine species able to grow in different bioclimates of Tunisia and to tolerate the edaphic variations of degraded environments to reforest. Thus, the aim of this study was to evaluate the relationships between climate and radial growth of two varieties of *P. pinaster* Arn. planted in the Middle Mountain of Kroumirie in northwest of Tunisia, using dendroecological approaches.

## 2 | MATERIALS AND METHODS

### 2.1 | Study site

The study site is located in the northwest of Tunisia (36°48′N, 8°48′E, 255 m, 492 m) in a humid Mediterranean climate characterised by rainy winters and dry summers (Figure 1). The monthly maximum and minimum temperatures and total precipitation data were collected from Ain Drahem meteorological station located approximately 10 km from the experimental site. The average annual precipitation was 1,534 mm/year. The mean annual temperature was 15.6°C, the hottest month being July (31°C) and the coldest one is January (4.4°C; Figure 1). The dry period usually extends from June to August. The understory, vegetation is dominated by *Erica scoparia* L. and *Halimium halimifolium* (L.) Willk. The soil is a balanced combination of loam, sand and clay.

### 2.2 | Materials

The study was carried out on two varieties of *P. pinaster* Arn. The origin of the seeds used in the provenance trial was identified. One is a native variety of Tunisia (*P. pinaster* var. *renoui*; Tabarka province, 36°57′N, 8°46′E, 200 m, superficial brown soil in sandstone, 1,044 mm/year), and the other is a native variety of Morocco (*P. pinaster* var. *maghrebiana*; Taza province, 33°52′N, 4°04′E, 1,600 m, superficial brown soil in limestone sandstone, 650 mm/year). These two varieties were planted in common garden in 1964 in Souiniet Arboretum in association with *P. nigra* species. These stands have not been managed and no fire has been detected since they were planted. Each variety is represented by 21 trees spaced 3 m apart.

### 2.3 | Methods

#### 2.3.1 | Tree morphological characterisation

In 2013, the diameter at breast height (DBH at 1.30 m) of all trees ($n$ = 21/variety) was measured using the equation: Diameter (cm) = circumference (cm)/$\pi$. Then, the height ($h$) was also measured using a 7 cm long perch placed vertically against the tree was to be measured, and calculated according to the following Equation (1) (Rondeux, 1993):

$$h = p.\left(\text{slopeOS} - \text{slopeOP}\right)/(\text{slopeOB} - \text{slopeOP}). \tag{1}$$

**TABLE 1** Survival rate (SR in %), height growth rate (HGR in m/year), radial growth rate (DGR in cm/year), diameter at breast height (DBH; in cm) and total height (*H* in m)

| Var. | SR (%) | HGR (m/year) | DGR (cm/ year) | *H* (m) | DBH (cm) |
|---|---|---|---|---|---|
| Maghrebiana | 90.5 | $0.385 \pm 0.02^{aa}$ | $1.235 \pm 0.14^{a}$ | $19.95 \pm 1.53^{a}$ | $56.6 \pm 7.12^{aa}$ |
| Renoui | 71.4 | $0.450 \pm 0.03^{ba}$ | $1.195 \pm 0.13^{a}$ | $19.57 \pm 2^{a}$ | $52.76 \pm 6.54^{ba}$ |

*Notes*. Values with the same letter are not statistically different ($p < 0.05$): HGR ($p = 0.0001 < 0.05$); DGR ($p = 0.378 > 0.05$); *H* ($p = 0.389 > 0.05$); DBH ($p = 0.0001 < 0.05$)

$^{***}$High significant difference.

In which: *p* = length of the perch; O: operator's eye; S: Summit; P: lower of the perch; B: upper end of the perch.

The survival rate was calculated by dividing the number of living trees by the total number of trees. Since planting, none of the original 21 trees (per variety) was replaced with another trees.

### 2.3.2 | Tree-ring data

In 2014, 11 dominant and healthy trees were selected and two cores per tree were collected at the base of the trunk using a Swedish increment borer (And Mattson ®). All cores were sanded and cross-dated by skeleton plot (Stokes & Smiley, 1968) under a binocular microscope; then, the ring widths were measured to the nearest 1/100 mm using a LINTAB6 measuring table and the TSAP software (Rinntech®). Cross-dating was checked by Arstan program (Holmes, 1994) and Dendrochronology Program Library in R (dplR), and chronologies were constructed using standard dendrochronological methods (Fritts, 1991; Merian and Lebourgeois, 2012). The chronologies were standardised by removing low- and intermediate-frequency variations, using a polynomial function (Lebourgeois, 2010).

Several statistics were calculated for the standardised chronologies. Mean sensitivity (MS) is a measure of the mean relative change between consecutive ring widths (Fritts, 1991). A high MS usually indicates a greater climate influence on tree growth. The first-order autocorrelation coefficients of the ring widths series (AC1) reflect the influence of the previous year's growth on the current year growth (Fritts, 1991). Rbar is the mean correlation coefficient between ring-width chronologies. It estimates the correlation between individual tree-ring series (Briffa & Jones, 1990). In addition, the expressed population signal (EPS) was calculated for site chronologies to verify the cross-dating and robustness of the climate signal (Wigley, Briffa, & Jones, 1984).

Then, correlations between tree growth and climate were calculated using monthly maximum, and minimum temperatures and total precipitation data collected from Ain Drahem meteorological station (1969–2013, alt. 676 m).

The relationship between climate and tree-ring widths was analysed using the bootstrapped response function (Fritts, 1991 using the program 3pBase (Guiot, 1991, Guiot & Gœury, 1996). The correlation coefficients were calculated over a period of 43 years (1970–2013). Analyses were done between residual tree-ring chronologies and monthly climatic variables (precipitation, maximum and minimum temperatures). We used 24 monthly climatic variables as regressors, starting from October of the previous year to September of the current year. The preliminary analysis was performed on 24 regressors. In order to improve the statistical significance of response functions, the climatic parameters were merged and number of regressors was reduced. The calculated response functions were limited at four significant regressors (precipitation of April; maximum temperature of May–June, minimum temperature of June–February, May–June). In fact, The bootstrapped regression is significant when the ratio, between the regression coefficient of each monthly variable and the associated standard deviation, reaches 95%, which is higher than 1.96 (Guiot & Nicault, 2010).

## 2.4 | Statistical analysis

The analysis of the variance of several parameters (DBH, height, radial growth, MS, AC1 and EPS) was tested using the generalised linear model (GLM) of the SAS statistical program. The multiple comparison of means was performed by using the Newman–Keuls test at a threshold of 5% (means with the same letters are not significantly different).

# 3 | RESULTS

## 3.1 | Survival rate and growth

The varieties showed different levels of survival rate. The highest survival rate was reached by *P. p.* var. *maghrebiana* (90%) while *P. p.* var. *renoui* recorded 71% ($p < 0.005$; Table 1). Values of mean ring widths and DBH at 1.30 m were higher for *maghrebiana* variety (1.235 cm/year, 500/100 mm/year and 56.6 cm, respectively). Height growth rate was higher for *renoui* variety by 0.450 m/year) compared to 0.385 m/year for *maghrebiana* variety. No significant difference was found in the total height (Table 2).

## 3.2 | Tree rings and growth rate

A decreasing linear trend is observed in ring-width series of individual trees for both varieties with higher values for the *maghrebiana* one (Figure 2). Curves of cumulative radial growth showed two phases: an initial phase of rapid and sustained growth during the first 8 years, followed by another phase of gradual slowed growth for both varieties (Figure 3).

Standardised chronologies showed a strong synchronous growth pattern among the two varieties, confirmed by a high

**TABLE 2** Number of trees sampled and dendrochronological characteristics of the raw ring-width data for two varieties of *Pinus pinaster* Arn.

| Varieties | Number of trees | Number of cores | Age at 1.30 cm | MG (1/100 mm) | MS | AC 1 | Rbar | EPS |
|---|---|---|---|---|---|---|---|---|
| Maghrebiana | 13 | 20 | 42 | 500.07[aa] | 0.208[a] | 0.85[a] | 0.39[a] | 0.90[a] |
| Renoui | 13 | 20 | 43 | 369.78[ba] | 0.208[a] | 0.81[a] | 0.38[a] | 0.91[a] |

*Notes*. Values were calculated using ARSTAN (Holmes, 1994) and R statistic (Mérian, 2012).
Values with the same letter are not statistically different ($p < 0.05$): MG ($p = 0.0001 < 0.05$); MS ($p = 0.498 > 0.05$), AC1 = 0.320 > 0.5); Rbar ($p = 0.411 > 0.05$); EPS ($p = 0.435 > 0.05$).
AC: first-order autocorrelation coefficient of ring widths; EPS: expressed population signal; MG: mean ring widths (1/100 mm); MS: mean sensitivity; Rbar: running mean inter-series correlation.
***High significant difference.

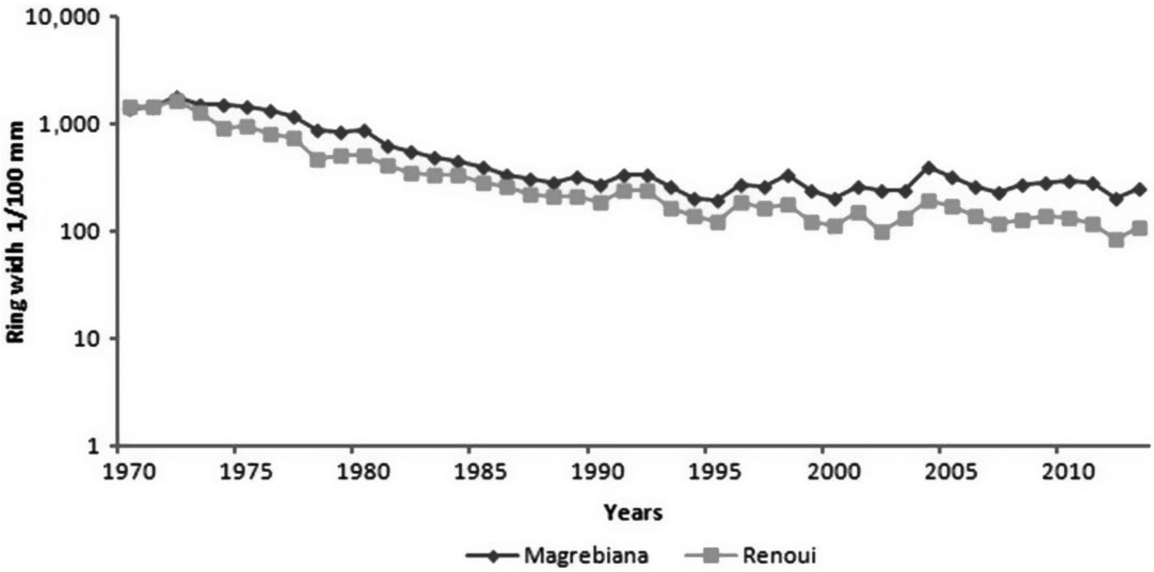


**FIGURE 2** Raw ring-width mean chronologies for *Pinus pinaster* var. *maghrebiana* and *P. pinaster* var. *renoui* varieties for the period 1969–2013

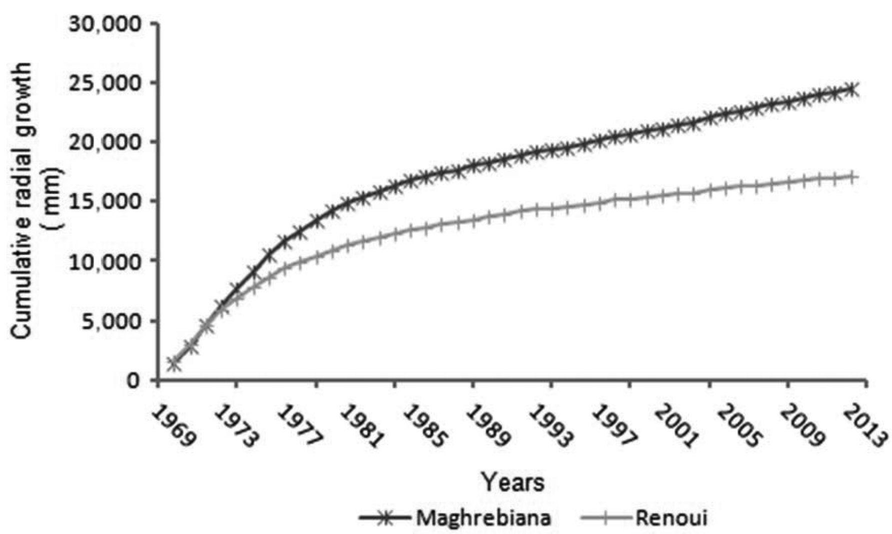


**FIGURE 3** Average cumulative radial growth curves of two *Pinus pinaster* varieties at 1.3 m for the period 1969–2013

degree of common variance over the whole period (Figure 4). This result was confirmed by the same values of MS (0.208). The high value of AC1 indicates a strong dependence on current growth of the previous year's growth for both varieties. As well, the EPS was above the critical value of 0.85 proposed by Wigley et al. (1984) (values indicating a high common signal). Rbar values showed a low common growth among individuals in a site chronology (Table 2).

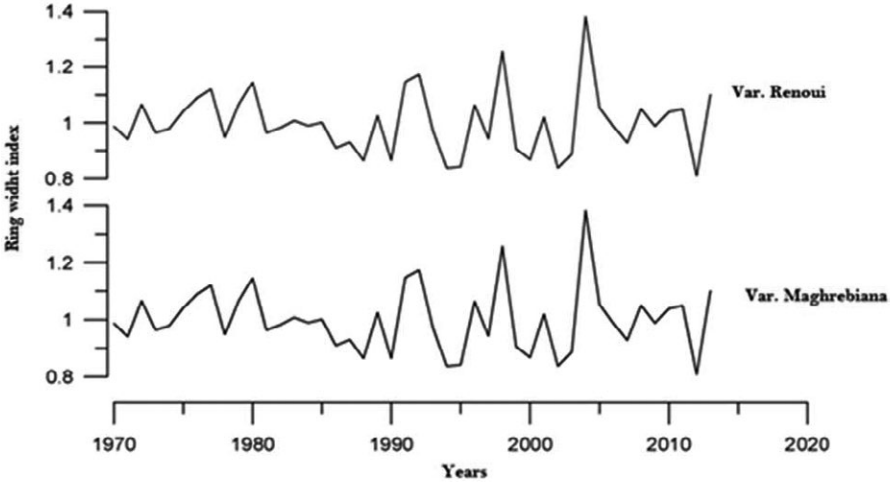


**FIGURE 4** Variations of ring-width residual chronologies of *Pinus pinaster* Arn. Varieties for the period 1969–2013

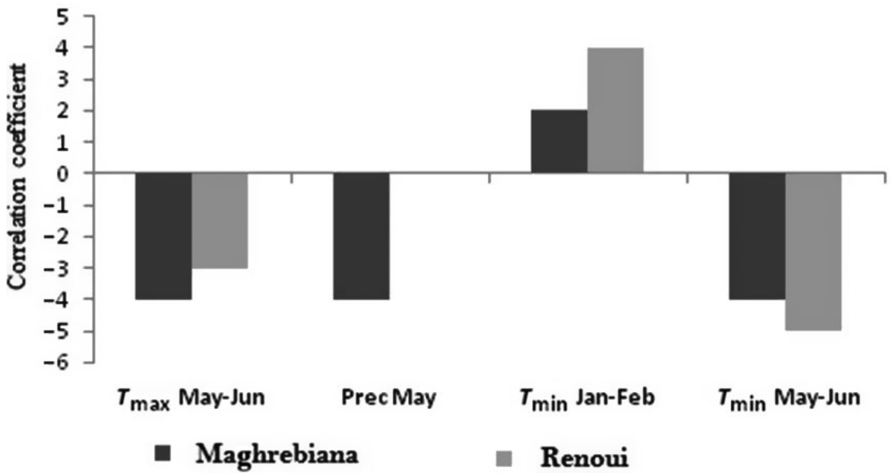


**FIGURE 5** Correlation coefficients between standardised ring-width series and precipitation, minimal and maximum temperatures. Standardised coefficients were obtained by dividing the mean correlations by their standard deviations after the bootstrap replications. They express the significance of monthly parameters.

### 3.3 | Climate–growth relationship

The bootstrap correlation analysis mentioned 4 months as significant: January, February, May and June. The ring width of both varieties showed a negative correlation with low and high temperatures (May–June). They were also positively correlated with low January–February temperatures. *Pinus p.* var *maghrebiana* was negatively correlated with May precipitation (Figure 5).

## 4 | DISCUSSION

The success achieved in *P. pinaster* at Souiniet exceeds that other pine species such as *P. nigra*, *P. radiata*, *P. halepensis* and *P. canariensis* (78%, 67%, 53% and 44%, respectively) planted in the same provenance trial in northwest of Tunisia (Khouja et al., 2004). *Pinus p.* var *maghrebiana* showed the highest survival rate. It is the best adapted to the ecological conditions of the Middle Mountains of Kroumirie. Benabid (1983) indicates that in the Rif Mountains the *maghrebiana* variety can be successfully introduced in the meso-Mediterranean belt and in the cooler supra-Mediterranean zone. Khouja et al. (2004) also showed that *P. pinaster* grows better compared to other species. In our study, we found an intra-specific difference, namely, that *P. pinaster* var. *maghrebiana* is more productive than for *renoui* variety by showing the largest radial growth and DBH. In addition, during the juvenile stage, growth was higher for the *maghrebiana* variety than for the *renoui* one. This result is in accordance with previous studies of Poupon (1974) and Aloui (2006). Growth rings are wide and well defined in the juvenile phase, reflecting the fast growing during the first 8 years, with a similar pattern in both varieties. Alaoui, Laaribya, and Gmira (2011) showed that the *maghrebiana* variety is more productive in a humid bioclimate than in sub-humid and semi-arid bioclimates. This may explain the adaptation and the important productivity of this variety in the Middle Mountains of Koumirie.

Studies of climate responses of this species showed that the MS of *P. pinaster* in the Middle Mountains of Kroumirie is higher than the MS found by Nefaoui (1996) in Morocco and is similar that one shown by Serre-Bachet (1982) in Provence in southern France. Moreover, MS was lower than that obtained by Bogino and Bravo (2008) in central Spanish forests and close to values found in Mediterranean pines such as *P. nigra* and *Pinus sylvestris* (Aloui, 2006; Seim et al., 2014).

Our results suggested that the temperature effect is more important than the precipitation in the studied area. Maritime pine radial growth in Kroumirie was predominantly affected by spring and early summer temperature. High temperatures in May and June could trigger an insufficient water balance and increase evapotranspiration, restricting tree growth formation (Martín-Benito, Rio, & Cañella, 2010). Pine radial growth was constrained by drought in the summer (June) in central and Southern Spain (Martín-Benito et al., 2010; Richter, Eckstein, & Holmes, 1991). Mediterranean pine species was considered well adapted to drought by decreasing growth as water availability decreases and increasing growth as conditions become favourable (Pasho, Camarero, & Vicente-Serrano, 2012). This strong negative correlation between spring temperature and *P. pinaster* growth was similar to results reported for three pine species (*P. halepensis*, *P. pinea* and *P. pinaster*) in Kroumirie (El Khorchani, Abdelhamid, & Zouhair, 2013) and was consistent with findings obtained for *P. pinaster* in south Portugal where tree radial growth was more sensitive to temperature than precipitation (Kurz-Besson et al., 2016).

The significant negative correlation of *P. pinaster* var. *maghrebiana* to May precipitation was found. Such a relationship was found in *P. nigra* in the central Apennines (Italy) and in the southern limit of its range (Tunisia) (Fkiri et al., 2018; Piermattei, Carbarino, & Urbinati, 2014) (Oberhuber, Stumböck, & Kofler, 1998). An excess of rainfall in May could also decrease incoming solar radiation, reduce photoassimilates and minimise carbohydrates available for cell-wall thickening. Vieira, Rossi, Campelo, Freitas, and Nabais (2014) demonstrated the influence of water availability in May on the xylogenesis and tracheid features in *P. pinaster* growing in Portugal. No significant relationship was found between summer precipitation and radial growth suggesting that cambial activity ceased during the summer (Cherubini et al., 2003).

A positive temperature effect in winter prior to the growing season may foster photosynthesis, increase the amount of fixed carbon before the growing season and promote an early resumption of cambial activity, thus increasing the length of the growing season (Creber & Chaloner, 1990; Hoch, Richter, & Körner, 2003).

Our results suggest that the Mountain variety of Morocco could be an appropriate provenance for restoring the forest systems of Kroumirie which are experiencing serious degradation problems.

## 5 | CONCLUSION

Adaptive forest management strategies recommended for the sustainable use of Mediterranean forests include the promotion of forestation and reforestation activities (using monospecific or diversified stands), the promotion of better-adapted tree species (drought tolerant or pests tolerant) and modifications in tree species composition (e.g., more diversified and resilient stands, multipurpose trees).

Our results show that *P. pinaster* var. *maghrebiana* from Morocco is well-adapted to the ecological conditions of the middle mountain of Kroumirie. It appears as a well-performing variety showing a significant capacity to grow compared to the Tunisian variety, and it opens up possibilities in tree breeding programmes even if its radial growth is constrained by May precipitation.

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## ORCID

*Sondes Fkiri* https://orcid.org/0000-0003-0813-4962

## REFERENCES

Alaoui, A., Laaribya, S., & Gmira, N. (2011). Production, croissance et modèles de conduite sylvicoles des principales essences (le pin maritime et le pin d'Alep) de reboisement au Maroc. *Kastamonu University Journal of Forestry Faculty*, *11*, 68–84.

Aloui, A. (1987). *Contribution à l'étude des accroissements et des productions des pins introduits aux arboreta de Souiniet, Zerniza, Choucha et Remel au Nord de la Tunisie* (p. 18) ronéo, unpublished.

Aloui, A. (2006). Etude comparative de la croissance en épaisseur des pins introduits à l'arboretum de Souiniet. *INRGREF Annals*, *8*, 105–117.

Belghazi, B., & Ezzahir, M. (1995). Dendrometric growth and ecological characteristics of classes of maritime pine (*Pinus pinaster* Sol. Var. magh.), Plantations in the Rif and Middle Atlas Oriental. *Annals of Forest Research (Rabat)*, *28*, 17.

Benabid, A. (1983). *Contribution à l'étude de l'écologie et de la productivité du pin d'Alep dans le versant nord du Haut Atlas (Forêt de Tanga)* (p. 129). Thése de Doc, Ing. En Ecologie terrestre, Univ. Sci. et Tech. du Languedoc.

Bogino, S. M., & Bravo, F. (2008). Growth response of *Pinus pinaster* Ait. to climatic variables in central Spanish forests. *Annals of Forests Sciences*, *65*, 506–518. https://doi.org/10.1051/forest:2008025

Boudy, P. (1952). *Guide du forestier en Afrique du nord. éditions* (p. 505). Paris, France: MAISON RUSTIQUE.

Briffa, K., & Jones, P. D. (1990). Basic chronology statistics an assessment. In E. R. Cook & L. Kairiukstis (Eds.), *Methods of dendrochronology* (pp. 137–152). Dordrecht, the Netherlands: Kluwer Academic Publisher.

Cherubini, P., Gartner, B. L., Tognetti, R., Braker, O. U., Schoch, W., & Innes, J. L. (2003). Identification, measurement and interpretation of tree rings in woody species from Mediterranean climates. *Biological Reviews*, *78*, 119–148. https://doi.org/10.1017/S1464793102006000

Creber, G. T., & Chaloner, W. G. (1990). Environmental influences on cambial activity. In M. Iqbal (Ed.), *The vascular cambium* (pp. 159–189). Research Studies Press Ltd., Taunton and Chichester, UK: John Wiley.

DGF (1995). General directorate of forestry, In *Results of the first national forest inventory Tunisia* (p. 87). Tunis, Tunisia: Ministry of Agriculture.

El Khorchani, A., Abdelhamid, K., & Zouhair, N. (2013). Evolution des relations croissance-climat de trois espèces de pin en Kroumirie (Nord-Ouest Tunisien). *Sécheresse*, *24*, 138–146.

El Khorchani, A., Gadbin-henry, C., Bouzid, S., & Khaldi, A. (2007). Impact of drought on growth of three forest species in Tunisia (*Pinus halepensis* Mill, *Pinus pinea* L. and *Pinus pinaster* Sol.). *Sécheresse Revue*, *18*, 113–121.

FAO and Plan Bleu (2013). *State of Mediterranean Forests* (p. 183). Rome: FAO.

Fkiri, S., Guibal, F., Fady, B., El Khorchani, A., Khaldi, A., Khouja, M. L., & Nasr, Z. (2018). Tree-rings to climate relationships in nineteen provenances of four black pines sub-species (*Pinus nigra* Arn.) growing in a common garden from northwest Tunisia. *Dendrochronologia Dendrochronologia*, *50*, 44–51. https://doi.org/10.1016/j.dendro.2018.05.001

Fritts, HC. (1991). Reconstructing large-Scale Climatic Patterns from Tree-Ring Data (p. 286). Tueson, AZ: University of Arizona Press.

Guiot, J. (1991). *The Bootstrapped Response Function. Tree-ring Bull*, *51*, 39–41.

Guiot, J., & Gœury, C. (1996). PPPBASE, a software for statistical analysis of paleoecological and paleoclimatological data. *Dendrochronologia*, *14*, 295–300.

Guiot, J., & Nicault, A. (2010). Méthodes de dendroclimatologie à l'échelle continentales: fonctions de réponse et fonctions de transfert. In S. Payette & L. Filion (Eds.), *La dendroécologie: Principes, méthodes et applications* (pp. 229–253). Laval, QC, Canada: Presses de l'Université de Laval.

Hoch, G., Richter, A., & Körner, C. (2003). Non-structural carbon compounds in temperate forest trees. *Plant Cell and Environment*, *26*(7), 1067–1081. https://doi.org/10.1046/j.0016-8025.2003.01032.x

Holmes, R. L. (1994). *Dendrochronology program library user's manual*. Tucson, AZ: Laboratory of Tree-Ring Research University of Arizona.

IPCC (2013). *Climate change 2013. The physical science basis*. Cambridge, UK: Cambridge University.

Khouja M., (2006). Bilan des essais de provenance de pin pignon installée en Tunisie. Fiche technique.

Khouja, M. L. (2003). *Etude de la diversité et de la variabilité génétique de 7 espèces forestières de première importance (Pin d'Alep, Pin brutia, Pin pignon, Pin noir, Chêne liège et Cyprès toujours vert). Projet fédérateur: Ecologie, sélections d'espèces et reboisement*. Rapport final, 1999–2003 (p. 96).

Khouja, M. L., Abdallah, H., Sghaier, T., Nouri, M., & Akrimi, N. (2004). Acclimatation de quelques espèces du pin au Nord de la Tunisie, Résultats et essai de comparaison à Souiniet. *Annales De l'INRGRE*, *6*, 139–151.

Khouja, M. L., & Najjar, E. (1989). Potentialités forestières dans le Nord de la Tunisie. In K. Mohamed Larbi N. Ezzeddine (Eds.), *Séminaire maghrébin d'agroforesterie* (pp. 108–118). Tunis, Tunisie: Jebel Oust.

Kurz-Besson, C. B., Lousada, J. L., Gaspar, M. J., Correia, I. E., David, T. S., Soares, P. M. M., … Gouveia, C. M. (2016). Effects of recent minimum temperature and water deficit increases on *Pinus pinaster* radial growth and wood density in Southern Portugal. *Front Plant Sciences*, *7*, 11–70. https://doi.org/10.3389/fpls.2016.01170

Le Maitre, D. C. (1998). Pines in cultivation: A global view. In D. M. Richardson (Ed.), *Ecology and biogeography of* Pinus (pp. 407–431). Cambridge, UK: Cambridge University Press.

Lebourgeois, F. (2010). *Principles and methods of dendrochronology*. (pp. 10–21). France: Forest Ecology Equipe Agro Paris Tech, ENGREF.

Lebourgeois, F., & Mérian, P. (2012). *Principes et méthodes de la dendrochronologie* (p. 90). Nancy, FranceCentre de Nancy, LERFOB, AgroParisTech.

Martín-Benito, D., del Rio, M., & Cañella, I. (2010). Black pine (*Pinus nigra* Arn.) growth divergence along a latitudinal gradient in Western Mediterranean Mountains. *Annals of Forest Sciences*, *67*(4), 401. https://doi.org/10.1051/forest/2009121

Mercurio, R. (2010). *Restauro della foresta mediterranea* (p. 368). Bologna, Italy: Clueb.

Mérian, P. (2012). POINTER et DENDRO: deux applications sous R pour l'analyse de la réponse des arbres au climat par approche dendroécologique. Outils et Méthodes. *Revue Forestière Française LXIV*, *6*, 789–798. https://doi.org/10.4267/2042/51116

Nefaoui, M. (1996). *Dendroécologie, productivité et dynamique de la croissance radiale du pin maritime naturel au Maroc*. PhD thesis, Vol. *2*. University of Aix-Marseille III.

Oberhuber, W., Stumböck, M., & Kofler, W. (1998). Climate–tree-growth relationships of Scots pine stands (*Pinus sylvestris L.*) exposed to soil dryness. *Trees*, *13*, 19–27. https://doi.org/10.1007/PL00009734

Pasho, E., Camarero, J. J., & Vicente-Serrano, S. M. (2012). Climatic impacts and drought control of radial growth and seasonal wood formation in *Pinus halepensis*. *Trees*, *26*, 1875–1886. https://doi.org/10.1007/s00468-012-0756-x

Piermattei, A., Carbarino, M., & Urbinati, C. (2014). Structural attributes tree-ring growth and climate sensitivity of *Pinus nigra* Arn. at high altitude: common patterns of a possible treeline shift in the central Apennines (Italy). *Dendrochronologia*, *32*, 210–219. https://doi.org/10.1016/j.dendro.2014.05.002

Poupon, D. (1974). *Principaux résultats de la station écologique de Souiniet*. Variété scientifique, 8.

Praciak, A., Pasiecznik, N., Sheil, D., van Heist, M., Sassen, M., Correia, C. S., … Teeling, C. (2013). *The CABI encyclopedia of forest*. Oxfordshire, UK: CABI.

Quézel, P., & Médail, F. (2003). *Ecologie et biogéographie des forêts du bassin méditerranéen* (p. 571). Paris, France: Elsevier.

Rapp, J. M., Silman, M. R., Clark, J. S., Girardin, C. A., Galiano, D., & Tito, R. (2012). Intra- and interspecific tree growth across a long altitudinal gradient in the Peruvian Andes. *Ecology*, *93*, 2061–2072. https://doi.org/10.1890/11-1725.1

Regato, P. (2008). *Adapting to global change: Mediterranean forests*. Malaga, Spain: IUCN Centre for Mediterranean cooperation.

Richter, K., Eckstein, D., & Holmes, R. L. (1991). The dendrochronological. Signal of pine trees (*Pinus* ssp.) in Spain. *Tree Ring Bulletin*, *51*, 1–13.

Rondeux, J. (1977). Estimation de la productivité Forestière : Principes et Méthodes. *Annales De Gembloux*, *83*, 5–17.

Rondeux, J. (1993). *La mesure des arbres et des peuplements forestiers* (p. 521). Gembloux, Belgium: Presses Agronomiques de Gembloux.

Schweingruber, F. H. (1996). *Tree rings and environment: Dendroecology* (p. 609). Bern, Switzerland: Paul Haupt.

Seim, A., Treydte, K., Trouet, V., Frank, D., Fonti, P., Tegel, W., … Büntgen, U. (2014). Climate sensitivity of Mediterranean pine growth reveals distinct east–west dipole. *International Journal of Climatology*, *35*, 2503–2513. https://doi.org/10.1002/joc.4137

Serre-Bachet, F. (1982). Analyse dendroclimatologique comparée de quatre espèces de pin et du chêne pubescent dans la région de la Gardiole près de Rians (Var, France). *Ecologia Mediterranea*, *8*, 167–183.

Sheppard, P. R. (2010). Dendroclimatology: extracting climate from trees. *Wiley Interdisciplinary Reviews: Climate Change*, *1*, 343–352. https://doi.org/10.1002/wcc.42

Stokes, M. A., & Smiley, T. L. (1968). *An Introduction to Tree-ring. Dating*. Tucson, AZ: University of Arizona Press.

Touchan, R., Anchukaitis, K. J., Meko, D. M., Sabir, M., Attalah, S., & Aloui, A. (2011). Spatiotemporal drought variability in northwestern Africa over the last nine centuries. *Climate Dynamics*, *37*, 237–252. https://doi.org/10.1007/s00382-010-0804-4

Vericat, P., Pique, M., & Serrada, R. (2012). *Gestión adaptativa al cambio global en masas de Quercus mediterráneos* (p. 172). Solsona, Spain: Forest Sciences Center of Catalonia.

Vieira, J., Rossi, S., Campelo, F., Freitas, H., & Nabais, C. (2014). Xylogenesis of *Pinus pinaster* under a Mediterranean climate. *Annals of Forest Science.*, *71*, 71–80. https://doi.org/10.1007/s13595-013-0341-5

Wigley, T. M. L., Briffa, K. R., & Jones, P. D. (1984). On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Applied Meteorology and Climatology*, *23*, 201–213. https://doi.org/10.1175/1520-0450(1984)023<0201:OTAVOC>2.0.CO;2