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Growth rates and responses to climate and aridity of Algerian Atlas pistachio populations

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ABSTRACT

The Atlas pistachio (*Pistacia atlantica*) is a minor hardwood species threatened due to overexploitation in some regions of the Maghreb, but it shows an extraordinary ecological plasticity inhabiting sites subjected from Mediterranean humid to arid conditions. To assess the drought tolerance of this understudied species, we sampled three Algerian populations along a N-S gradient of increasing aridity: Theniet el Had (sub-humid site, H), Djelba (semi-arid or dry site, D) and Béchar (arid site, A). First, ring-width chronologies were built. Second, correlations between ring-width indices, climate variables, a drought index and teleconnection indices (NAO, North Atlantic Oscillation; MOI, Mediterranean Oscillation index; SOI, Southern Oscillation Index; SaOI, Sahara Oscillation Index) were calculated. A high precipitation in the previous autumn and winter enhanced radial growth of Atlas pistachio and also high June precipitation in the wettest site H. In the driest site A, high maximum temperatures in spring constrained growth. High minimum temperatures in late summer and early autumn enhanced growth in sites D and A, which showed similar year-to-year growth variability ($r = 0.426$, $p = 0.015$, period 1980–2011). Correlations with a drought index peaked in the driest site A from September to December. Positive relationships between growth and drought indices in spring and autumn suggest a bimodal growth pattern. The three sites showed positive correlations between growth indices and the April MOI. However, negative relationships were found for January NAO or MOI and spring indices (June NAO, May SOI) in site H. Here, growth rates were negatively related to the SaOI. The Atlas pistachio shows a remarkable drought tolerance and its climate-growth relationships indicate plastic growth responses to precipitation variability.

1. Introduction

Climate warming is leading to particularly warmer and drier conditions in some regions of the world (Padrón et al., 2020). Such aridification trend is evident in some countries of the southern Mediterranean Basin where record droughts are forecasted during the 21st century under high-emission scenarios (Satoh et al., 2022). These forecasts are worrying for Maghreb countries which have been negatively affected by historically unprecedented droughts since the 1980s (Touchan et al., 2011). Indeed, several forests ecosystems of Algeria and Morocco have shown recent dieback and mortality episodes in response to hotter and severe droughts (e.g. Heydari et al., 2023; Kherchouche et al., 2012; Navarro-Cerrillo et al., 2019; Sarmoum et al., 2024). These studies mainly focused on widely distributed, major tree species such as mountain Atlas cedar (*Cedrus atlantica*), pines and oaks, but we lack information on minor hardwood, deciduous tree species which may show a high drought tolerance under more arid climate conditions.

Drought-tolerant hardwood tree species with moderate growth rates and a long-term capacity for carbon storage as woody tissues, i.e. forming dense wood, are good candidates for climate-smart rewilding (Camarero et al., 2023a). For instance, the deciduous terebinth (*Pistacia terebinthus* L.), which forms ring-porous wood, showed notable drought tolerance and growth rates in NE Spain (Camarero et al., 2024). A similar species, but widely distributed in semi-arid and arid regions of the Maghreb, is the Atlas pistachio (*Pistacia atlantica*), which may constitute a climate-smart tree species under more arid conditions. This tree species is found from relatively humid locations near the Mediterranean coast of NW Africa (annual precipitation ca. 600 mm) to

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semi-arid and arid sites (annual precipitation ca. 100 mm) near ephemeral streams (wadis) in the Sahara (Monjauze, 1968; Ozenda, 1991; Quézel and Médail, 2003). Therefore, such distribution across an ample aridity gradient indicates a high ecological plasticity and potential drought tolerance. Moreover, its conservation status is delicate because its populations show a continuous decline in some arid areas of the Maghreb due to overexploitation for firewood, domestic uses as medical remedy (resin) and also because of desertification (Benradje et al., 2012).

Long-term climate and growth data are required to assess drought tolerance of tree species in the field (Camarero et al., 2021). Tree-ring width data are suitable proxies of the responsiveness and tolerance of tree species to drought and aridity at seasonal to annual resolution (Fritts, 1976). Here, we studied the radial growth responses to climate and drought severity of three Algerian Atlas pistachio populations along a wide aridity gradient. Specifically, we aimed: (i) to assess their growth rates using precisely dated tree-ring width series, and (ii) to quantify their climate- and drought-growth relationships. Climate-growth correlations are framed according to major atmospheric circulation patterns affecting the climate of the Maghreb. These patterns were characterized using teleconnection indices such as the North Atlantic Oscillation (NAO) index, which influences winter-spring climate conditions in the western Mediterranean Basin (Hurrell, 1995). We expect a higher responsiveness of Atlas pistachio growth to precipitation, drought severity and teleconnection indices in the driest site. We also expect that climate-growth relationships will differ along the aridity gradient, indicating a facultative shift from unimodal to bimodal growth patterns in response to spring and autumn precipitation peaks (Mitrakos, 1980; Valeriano et al., 2023).

2. Material and methods

2.1. Study sites

We selected three study sites situated in Algeria and showing contrasting aridity, from more humid to more arid conditions: the humid Theniet el Had site (hereafter site H), the dry Djelba site (hereafter site D) and the arid Béchar site (hereafter site A) (Fig. 1). Climate conditions range from sub-humid Mediterranean (H), to dry semi-arid (D) and subtropical arid (A). The mean annual temperature oscillates from 16.6 ºC in site H (ranges of monthly means 7.1–27.7 ºC) to 15.8º C in site D (range 5.6–28.2 ºC) and 21.8 ºC in site A (range 10.1–34.5 ºC). The annual precipitation ranges from 561 mm (H) to 308 mm (D) and 106 mm (A; Fig. 1), with a dry period lasting from June/July to October (sites H and D) or throughout the whole year (site A). Precipitation is bimodal and peaks in winter-spring (January, March) and autumn (September, November). Soil moisture recharge occurs during winter in sites H and D (Fig. S1).

The main tree and shrub species of each site characterize different climate conditions, with Mediterranean conifers and oaks (*C. atlantica*, *Pinus halepensis* Mill., *Quercus afares* Pomel, *Quercus ilex* L.) in the most humid H and D sites and deep-rooted shrubs (*Ziziphus lotus* (L.) Lam.) and sub-shrubs (*Artemisia herba-alba* Asso.) of arid/semi-arid Mediterranean steppes in site A (Table 1). In site H, soils are of colluvial type, whilst soil texture in sites D and A is sandy to silty-clayey and sandy-loamy to clay-silty-sandy, respectively. Local disturbances include wildfires in site T and overexploitation due to firewood demand in site A.

2.2. Study species

The Atlas pistachio or Atlantic terebinth (Anacardiaceae, *Pistacia atlantica* Desf.) is a deciduous, dioecious tree growing up to 7–9 m in height. It forms pinnate leaves which flush in March and fall in November. It is considered a slow-growing tree, but studies on their radial growth rate are still scarce (but see Ifticene-Habani and Messaoudène, 2016; Ifticene-Habani and Fatiha, 2018). Its wood varies from semi-diffuse to ring-porous and it forms distinct rings. It is found in the Canary Islands, across the Maghreb, in the Turkish-Iranian Plateau and in Azerbaijan (Zohary, 1952, 1996). In NW Africa, it inhabits oak woodlands (e.g. holm oak, *Quercus ilex* L.), coexists with conifers (e.g. Atlas cedar, *Cedrus atlantica* Manetti) or forms scattered small populations. The species shows a great ecological plasticity and it grows in open to mid-shaded sites with very different soil types and in contrasting topographical locations from rocky cliffs to temporarily damp depressions (Charco, 2001; Rezaeyan et al., 2009). It has been used as a source of forage, firewood, fruits, resin or for grafting, being overharvested in arid regions such as S Algeria (Belhadj, 2007; Benhassaini et al., 2007; Amara, 2014). Regionally, it is a threatened species due to anthropogenic use and desertification, and globally is considered a near threatened species (Rankou et al., 2018).

2.3. Field sampling

In the field, we selected mature individuals, identified their sex and measured their height and horizontal crown projection using a range-finder laser and tapes. We tried to sample a similar number of males and females in each site because sex can influence growth rates and responsiveness to climate (Rozas et al., 2009). The position and elevation of each sampled individual was taken with a GPS (± 5 m resolution). We took one core per individual at 1.3 m using a Pressler increment borer. In each site, from 21 to 36 mature individuals were measured and cored across sampling areas ranging from 1 to 2 ha (Table 1). Some trees were sampled in wadis in the case of the driest sites D and B, whereas they were located in N- and S- facing mid slopes in the wettest T site.

2.4. Climate data, drought and teleconnection indices

We obtained climate data with monthly resolution (Tmax, mean maximum temperature; Tmin, mean minimum temperature; Prec, total precipitation) from the following local stations located near the study sites: Tiaret (35º 21' N, 1º 28' E, 1127 m, period 1979–2011), Djelfa (period 1972–2011; see coordinates in Table 1) and Béchar (period 1965–2011; see coordinates in Table 1).

To characterize site aridity, we used the 30-arc gridded aridity index defined as the ratio of precipitation over evapotranspiration, i.e. the precipitation available in relation to atmospheric water demand (Zomer et al., 2022). Values of the index in the ranges 0.03–0.2, 0.2–0.5 and 0.5–0.65 correspond to arid, semi-arid and dry sub-humid climate conditions, respectively. We also calculate climatic water balances following Willmott et al. (1985).

To assess drought severity and duration, we obtained 1- to 24-month long monthly values of the 0.5º-gridded Standardised Precipitation-Evapotranspiration Index (SPEI) drought index from the SPEI Global Drought Monitor webpage (https://spei.csic.es/home.html). The SPEI is a multi-scalar index calculated using cumulative climatic water balance which considers both precipitation and evapotranspiration (Vicente-Serrano et al., 2010). Negative and positive SPEI values indicate dry and wet conditions, respectively.

High (low) NAO values in winter are linked to low (high) precipitation over this region (Hurrell et al., 2003) and, therefore, lower (higher) tree growth rates (Camarero, 2011). In addition to the NAO (Jones et al., 1997), we also considered other three teleconnection indices affecting climate conditions over the western Mediterranean Basin, namely the Mediterranean Oscillation Index (MOI), the Southern Oscillation index (SOI) and the Sahara Oscillation Index (SaOI). The MOI is the normalized pressure difference between Algiers and Cairo and it has been shown to affect precipitation in the central Mediterranean Basin (Conte et al., 1989; Palutikof et al., 1996). The NAO and MOI show similar patterns with positive (negative) phases characterized by higher (lower) sea level pressure anomalies over the Mediterranean

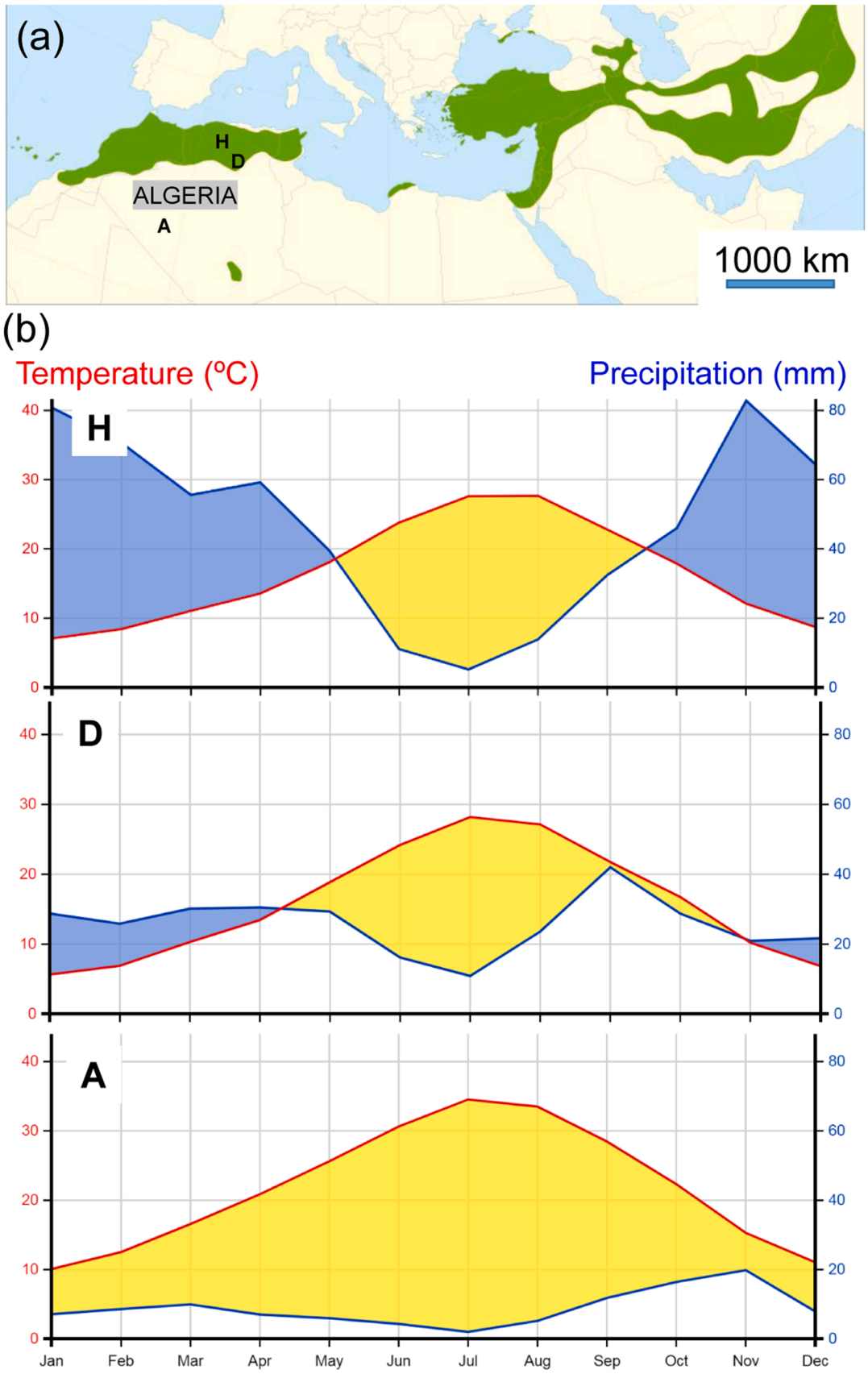


Fig. 1. Location of the three study sites (H, D and A) in Algeria and with respect to the (a) *P. atlantica* distribution area (green patches) and (b) site climate diagrams. See sites' codes in Table 1. The distribution map for *P. atlantica* was obtained from: https://commons.wikimedia.org/wiki/File:Pistacia_atlantica_range.svg.

Table 1
Features of the three study sites. Values are means ± SE.

Site (code)	Latitude	Longitude	Elevation (m a.s.l.)	Slope (°)	No. sampled female / male individuals	Diameter at 1.3 m (cm)	Height (m)	Aridity Index	Companion plant species
Theniet el Had (H)	35° 51' N	1° 59' E	1263 ± 4	29	15 / 17	30.5 ± 2.9	8.1 ± 0.7	0.64	*Cedrus atlantica, Quercus ilex, Quercus afares, Pinus halepensis, Juniperus phoenicea*
Djelfa (D)	34° 37' N	3° 41' E	709 ± 9	0	12 / 24	46.9 ± 1.5	11.7 ± 0.3	0.36	*Ziziphus lotus, Artemisia herba-alba, Stipa tenacissima*
Béchar (A)	31° 58' N	1° 37' W	897 ± 22	0	12 / 9	32.6 ± 2.3	10.5 ± 0.5	0.09	*Z. lotus, A. herba-alba, Acacia raddiana, Retama raetam*

(Criado-Aldeanueva and Soto-Navarro, 2020). The SOI is calculated as the series of standardized differences in monthly standardized sea level pressure between Tahiti and Darwin (Australia) (Ropelewski and Jones, 1987). It has been found that year-long droughts starting in winter and spring affected climate conditions and forest growth in NE Spain during periods with high SOI values (Rodó et al., 1997; Camarero, 2022). The SaOI is calculated as the difference between the normalized pressure of the Azores High (Azores) and the Saharan depression (Niamey) and it is related to MOI and NAO, particularly in winter (Khomsi et al., 2020). Monthly (NAO, MOI, SOI) and annual (SaOI) series of these indices were obtained from the CRU webpage (https://crudata.uea.ac.uk/cru/data).

2.5. Tree-ring width data: processing samples and building chronologies

Cores were air dried in the laboratory, glued onto wooden supports and carefully sanded using sandpapers of increasingly finer grain until tree-ring boundaries were visible. Then, the samples were visually cross-dated under the stereomicroscope (Stokes and Smiley, 1968). The widths of tree rings were measured with a 0.01 mm resolution using a Lintab-TSAP system (RINNTECH, Heidelberg, Germany) in correctly dated samples. Cross-dating was checked using the software COFECHA, which calculated shifted correlations between growth indices of each individual series and the mean site series (Holmes, 1983).

To calculate climate– and drought–growth correlations, individual ring-width series were transformed into mean site series of ring-width indices through detrending (Fritts, 1976). Ring-width series were detrended by fitting *x*-year cubic smoothing splines with a 50 % frequency response cut-off, where *x* was 2/3 of the mean series length. The resulting series of dimensionless ring-width indices were pre-whitened by fitting auto-regressive models, and bi-weight robust means were computed to obtain residual site series (chronologies) retaining annual to decadal growth variability.

Finally, several statistics were calculated for the common interval 1980–2011 to characterize the tree-ring series (Briffa and Jones, 1990), namely: the mean tree-ring width; the first-order autocorrelation (AR1) of ring widths, which measures growth persistence; the mean sensitivity (MS) of ring-width indices, which measures relative changes in width between consecutive rings; and the mean correlation between series of ring-width indices (Rbar). We also calculated the Expressed Populations Signal (EPS) to assess the coherence and replication of each site series or chronology (Wigley et al., 1984). It was assumed that intervals with EPS ≥ 0.85 corresponded to coherent and well-replicated mean series. The processing and detrending of tree-ring width series was carried out using the package dplR (Bunn, 2008, 2010; Bunn et al., 2023) in the R statistical software (R Core Team, 2023). The "dcc" function from the treeclim R package was used to calculate Pearson correlations between monthly values of climate variables, teleconnection indices or SPEI and the mean site series of ring-width indices (Zang and Biondi, 2015). These correlation analyses were carried out from the prior October to the current September, when annual radial growth was assumed to be almost complete. Climate data from the three local meteorological stations were used to calculate the correlations with each of the three *P. atlantica* tree-ring chronologies.

2.6. Data analyses

To compare tree features (elevation, diameter, height) or tree-ring width variables between females and males within each site we used *t* tests after checking the normality of variables. To assess trends in tree-ring width, the Mann–Kendall (MK) test was employed because it can detect trends in time series of non-parametric data and it is not very influenced by extreme values. In addition, Pearson correlations were used to compare site ring-width chronologies and to calculate relationships between growth indices, climate variables and the drought index.

3. Results

3.1. Tree size and growth rates

No differences in elevation or tree size were found between females and males within each site, excepting in the case of diameter which was lower in females than in males in the driest site A (Table S1).

Growth rates were the highest (1.84 mm) in the wettest sub-humid site H and the lowest (1.13 mm) in the driest arid site A, with intermediate values (1.45 mm) in the semi-arid site D (Table 2). The first-order correlation was low in site D, whereas the mean sensitivity peaked in site D. Rbar and EPS were also the highest in the D site and their values indicated well-replicated series in the three sites.

Both sites D and A showed negative and significant trends in tree-ring width (MK = −0.33, $p = 0.0006$, and MK = −0.49, $p < 0.0001$, respectively), but this was not the case of site H (MK = −0.13, $p = 0.20$; Fig. 2). Considering the common period (1980–2011), only the mean residual chronologies of sites D and A, separated by ca. 600 km, showed a positive and significant correlation ($r = 0.426$, $p = 0.015$).

3.2. Responses of growth indices to climate variables, drought and teleconnection indices

In site H, a high precipitation in the previous October and in current January and June enhanced growth (Fig. 3). Wet conditions in the prior October also enhanced growth in site A. High rainfall in March-April improved growth rates in sites D and A. High minimum temperatures in the prior winter (January) and current late summer (August, September) improved growth in sites D and A. High maximum

Table 2
Tree-ring data and statistics calculated for the common interval 1980–2011. Values are means ± SE.

Site	Time span	No. individuals	Tree-ring width (mm)	AR1	MS	Rbar	EPS
H	1968–2011	20	1.84 ± 0.17	0.59 ± 0.03	0.28 ± 0.01	0.38	0.88
D	1980 – 2011	35	1.45 ± 0.04	0.28 ± 0.04	0.47 ± 0.02	0.41	0.90
A	1969 – 2011	21	1.13 ± 0.06	0.52 ± 0.04	0.35 ± 0.02	0.34	0.86

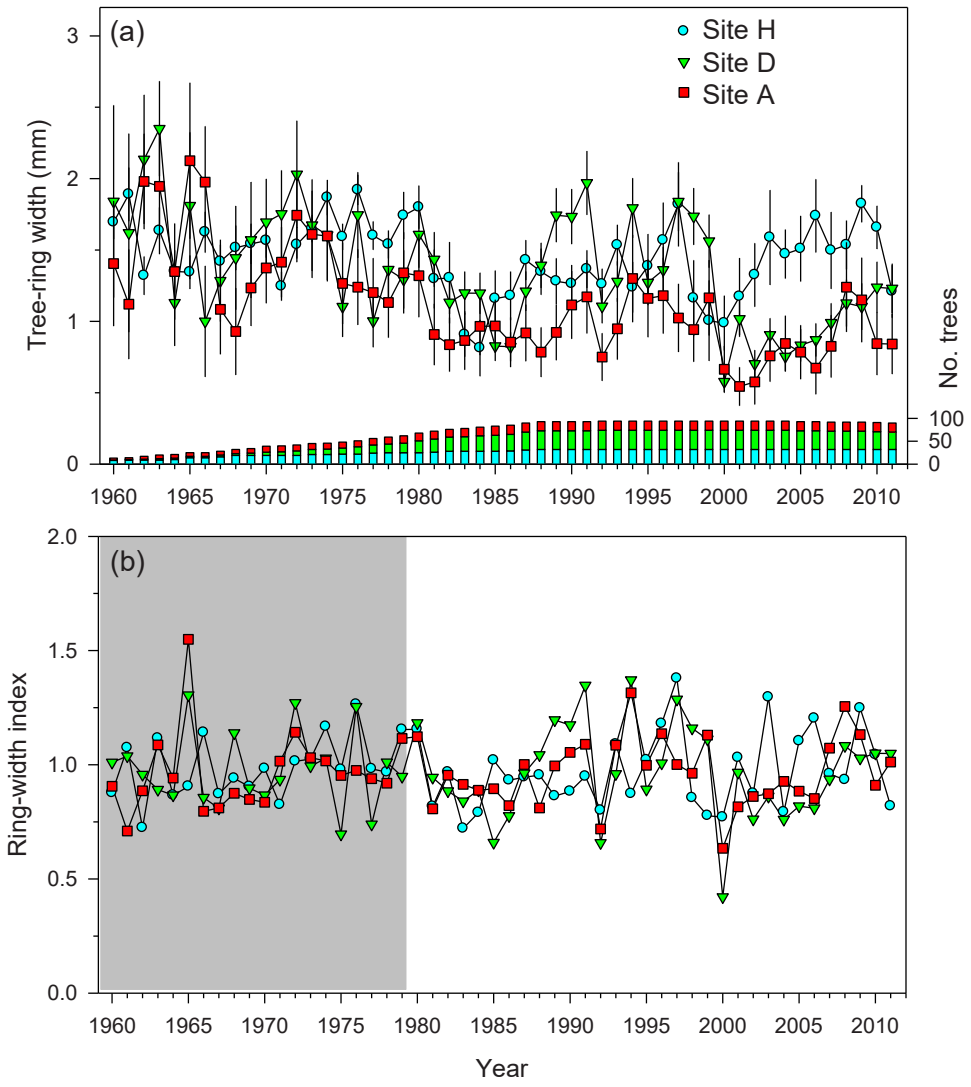


Fig. 2. Mean series of (a) tree-ring width and (b) ring-width indices. In plot (a), values are means ± SE. In plot (b), the best-replicated period (1980–2011) is indicated with the white background.

temperatures in site D lead to higher growth indices, but, in general, the impact of this variables was negative as indicated the negative correlations between growth indices and March (site A) or June (site H) maximum temperatures.

The highest correlation ($r = 0.51$) between growth indices and the SPEI was found for 4-month December SPEI (i.e. droughts lasting from September up to December) in the driest site A (Fig. 4). This was followed by the wettest site H ($r = 0.45$), with high correlations for long droughts, specifically for the 12-month December SPEI. In the intermediate D site, the correlation peaked ($r = 0.41$) for 5-month October SPEI values. Overall, Atlas pistachio growth responded to droughts lasting from June to December

Considering the mean monthly correlations of growth indices with SPEI, a bimodal pattern is observed with higher autumn values in sites H and D, but higher spring values in site A (Fig. 5). The ratios between spring and autumn mean growth–SPEI correlations were 0.80, 0.65 and 1.40 in sites H, D, and A, respectively.

We found negative correlations with previous winter MOI in sites H and D and positive correlations with April MOI in all sites (Fig. S2). Analogously, H and D sites also showed negative correlations with winter NAO indices, and also with the June NAO index in site H. The March SOI showed a negative correlation with growth indices of site H. Lastly, the annual SaOI and the growth indices of site H were negatively correlated ($r = -0.45$, $p = 0.012$; Fig. 6).

4. Discussion

The presented findings allow supporting the main hypothesis because we found the greatest growth responsiveness of the Atlas pistachio to the drought index in the driest site A. In this arid site, growth was also constrained by spring warm conditions suggesting higher evapotranspiration rates leading to water deficit, reduced turgor and cambial activity, i.e. decreasing xylem cell division and expansion (Köcher et al., 2012). Interestingly, the highest mean sensitivity, Rbar and EPS values were recorded in the semi-arid D site suggesting that growth variability between consecutive rings and coherence among coexisting individuals do not necessarily peak in the driest site, which may show too stressful conditions, and strong growth dependence on local soil water reserves and episodic rain events. Further studies should consider analyzing isotope ratios in xylem wood and soil water ($\delta^{13}C$, $\delta^{18}O$, $\delta^{2}H$) to disentangle how the Atlas pistachio responses to climate depend on seasonal water and nutrient uptake from different soil depths. For instance, similar analyses allowed uncovering that the evergreen *Pistacia lentiscus* shows a conservative water use and it is able to extract water from deep (> 40 cm) soil sources during dry periods (Moreno-Gutiérrez et al., 2012). The evergreen *P. lentiscus* forms

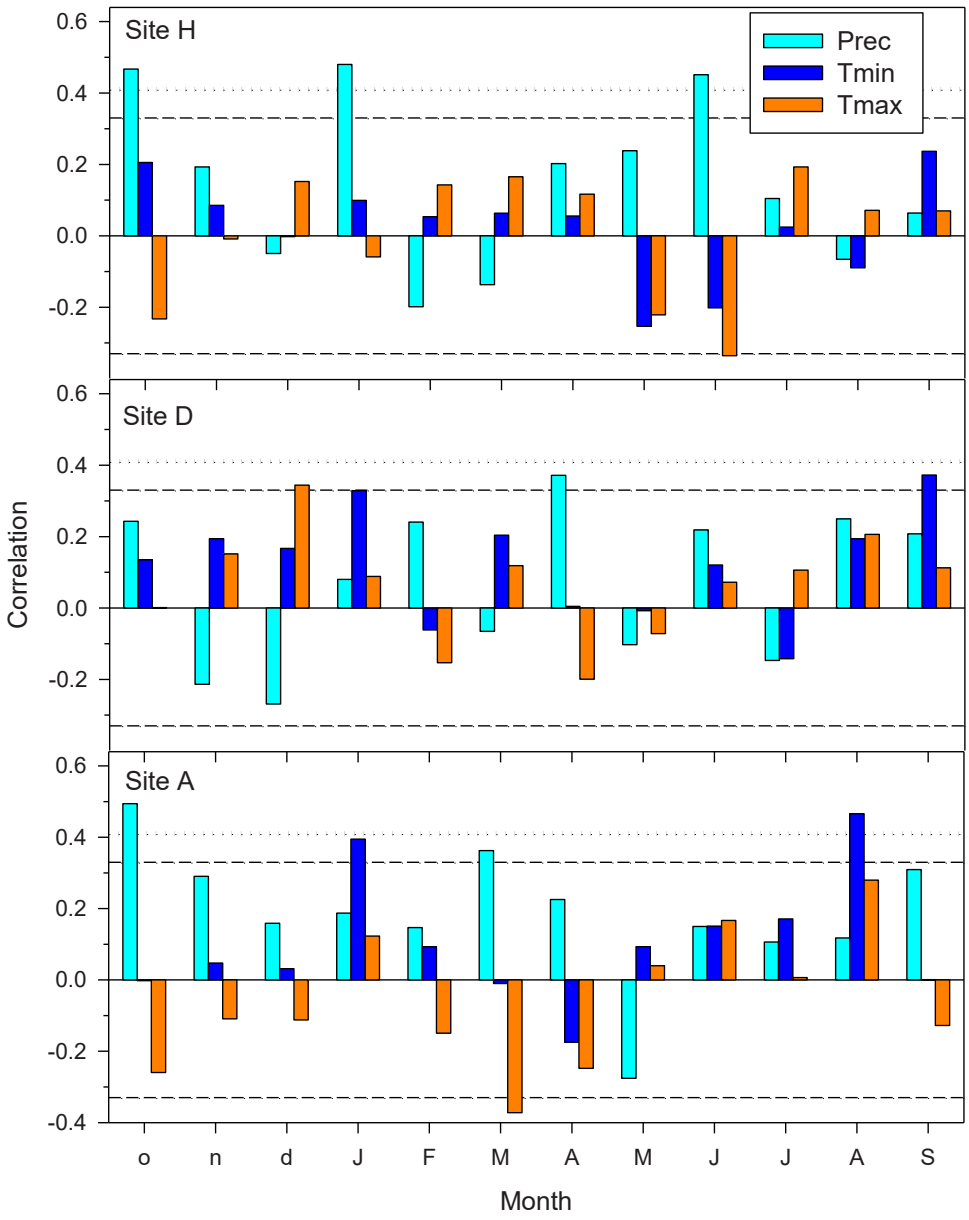


Fig. 3. Pearson correlations calculated by relating site series of ring-width indices and monthly climate variables (Prec, total precipitation; Tmin, mean minimum temperature; Tmax, mean maximum temperature). The window of analyses goes from previous October to current September with the previous- and current-year months abbreviated by lowercase and uppercase letters, respectively. Horizontal dashed and dotted lines show the 0.05 and 0.01 significance levels, respectively.

semi-ring porous wood and follows a strategy of drought-avoidance by water-spending and by maintaining leaf biomass until most hydraulic conductivity is lost (Villar-Salvador, 2000; Vilagrosa et al., 2003).

Overall, our results confirm that the study species shows a remarkable drought tolerance and very plastic growth responses to climate variability. These findings agree with previous local studies on this species (Ifticene-Habani and Messaoudène, 2016; Ifticene-Habani and Fatiha, 2018). Moreover, the negative association between growth indices and spring or summer maximum temperatures in the arid and sub-humid sites, respectively, indicate different cambial phenology. This is corroborated by the mean monthly correlations with the SPEI suggesting a bimodal growth pattern (cf. Camarero et al., 2023b; Valeriano et al., 2023) in the wet sites H and D. In contrast, site A could show a more unimodal pattern and, probably, an earlier cambial onset. These inferences could be tested using either periodic wood sampling (xylogenesis) or automatic dendrometers combined with records of climate in situ data.

Previous dendroecological studies on Mediterranean *Pistacia* species (*P. lentiscus*, *P. terebinthus*) found that wet winter-spring conditions improved their growth (Gazol et al., 2017; Camarero, 2018; Tamudo et al., 2024). The evergreen *P. lentiscus* showed a late bud-break (April-May) and a late cessation of shoot formation (August) in NE Spain, whereas the deciduous *P. terebinthus*, more similar to the Atlas pistachio (*P. atlantica*), presented a shorter period of shoot growth with a clear spring peak (Castro-Díez et al., 2003). In *P. terebinthus*, growth was enhanced by high precipitation in spring and early summer and cool conditions in summer (Camarero, 2018). In this species a high precipitation in June enhanced radial growth but also increased vessel density, probably increasing the hydraulic conductivity before summer drought starts (Camarero et al., 2024). It is plausible that the Atlas pistachio shows a major growth peak in spring but is also able to take advantage of mild-wet conditions in autumn when soil-moisture recharge starts. This would explain the positive responses to minimum temperatures in late summer and early autumn.

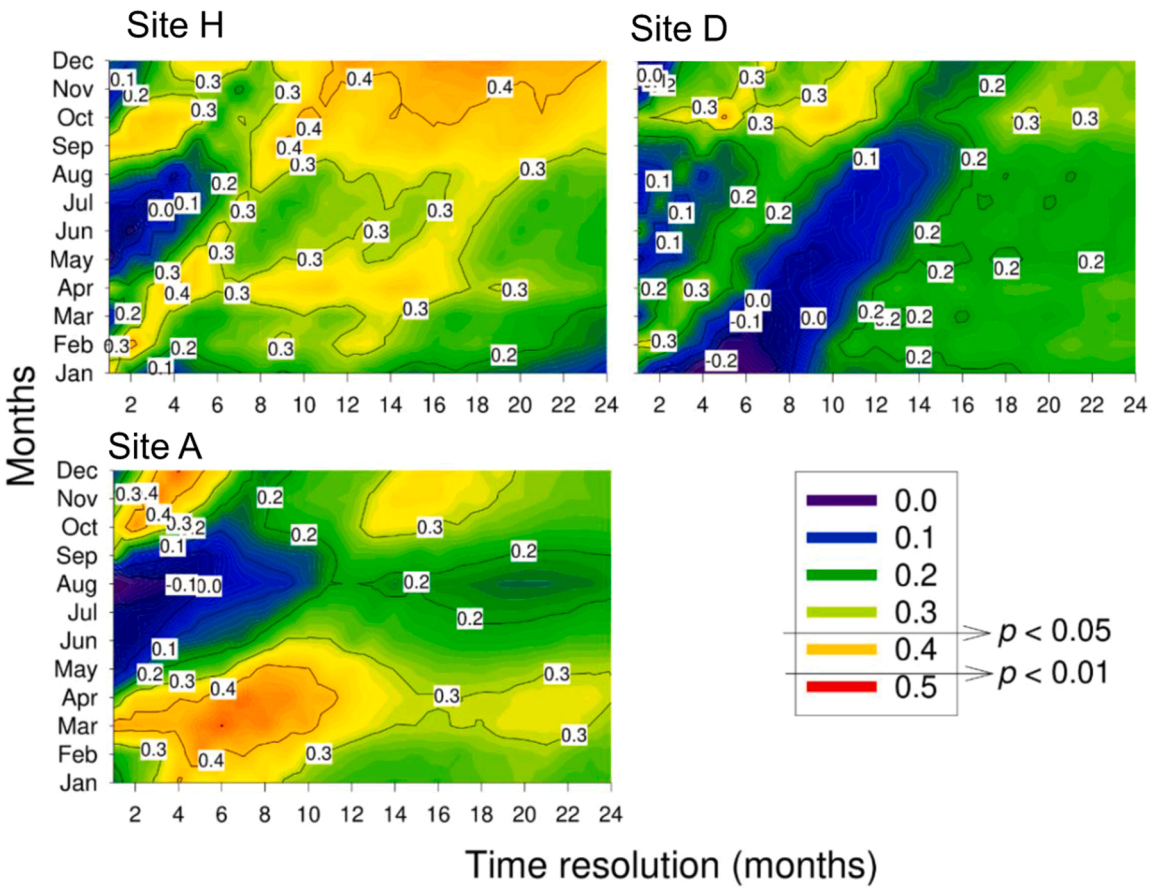


Fig. 4. Pearson correlations (color scale) calculated by relating site series of ring-width indices and monthly values of the SPEI index. The monthly SPEI values are calculated for time scales from 1 to 24 months (x axes). In the legend, arrows indicate thresholds for 0.05 and 0.01 significance levels.

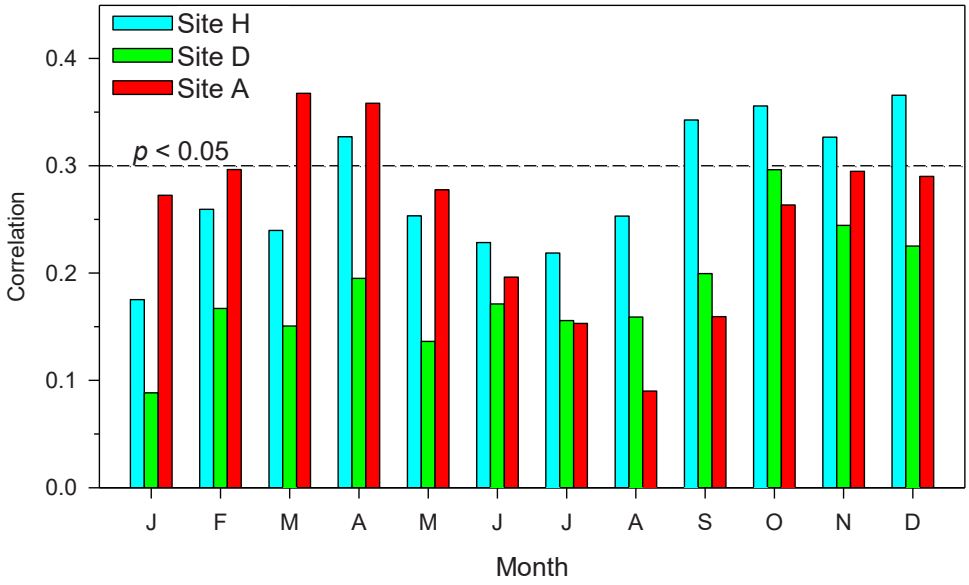


Fig. 5. Mean monthly correlations between site series of ring-width indices and the SPEI drought index. The horizontal dashed line shows the 0.05 significance level.

The two driest sites showed a high growth coherence despite being separated by a big distance. However, the sub-humid and semi-arid H and D sites, respectively, showed more significant correlations with teleconnection indices (MOI, NAO, SOI, SaOI). This suggests that Atlas pistachio growth and probably ecosystem productivity of these two sites are more linked to climate-atmospheric circulation patterns dominating over the western Mediterranean Basin, whilst growth in the remote arid site A depends more on local soil and topographic conditions. Therefore, the responsiveness of interannual tree-ring growth variation to large-scale climate drivers may differ in the core and in the edge of the species distribution range. Soil texture and fertility should be also measured in future studies on Atlas pistachio growth responses to climate because

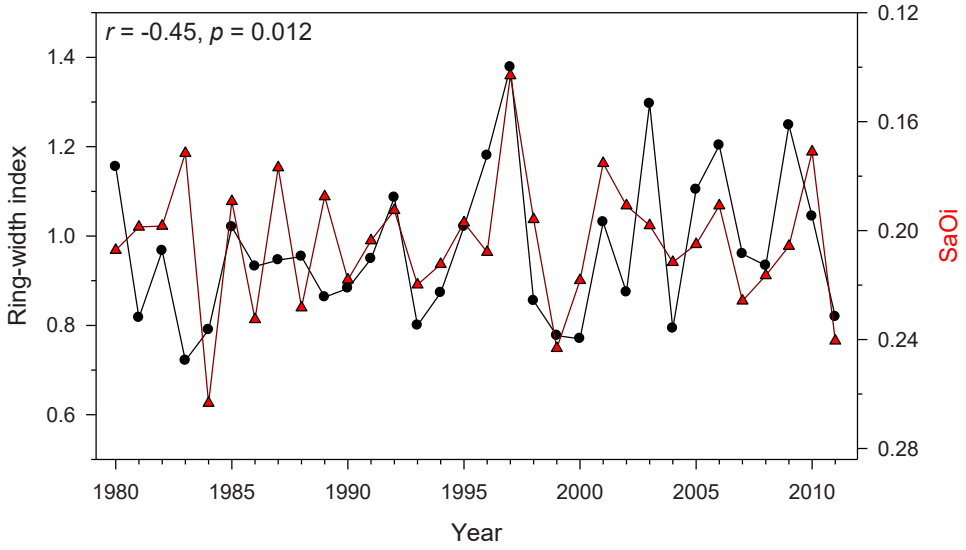


Fig. 6. The Saharan Oscillation Index (SaOI, red symbols) is tightly connected with the Atlantic pistachio ring-width indices (black symbols) measured in site H. Note the reverse y-axis range in the case of the SaOI.

they could explain its plastic behavior. For instance, seedlings of the study species showed higher growth and survival rates on silty than in sandy soils (Rezaeyan et al., 2009). In addition, the species forms shallow roots in sandy soils, but deeper and more extensive roots including a strong taproot are formed in sites with loamy soils (Limane et al., 2014). Again, the differential access to shallow and deep water sources could explain a facultative shift between unimodal and bimodal growth patterns.

5. Conclusions

Tree-ring analyses allowed characterizing the plastic growth responses of the understudied Atlas pistachio to climate variability, teleconnection indices and drought severity. This species showed a high drought tolerance linked to a coupling to regional climate-atmospheric patterns in the sub-humid site H or to local changes in precipitation and water demand (driven by elevated temperatures) during the early growing season in the arid site A. It is plausible that this deciduous species follows a conservative water use and uses different soil water sources depending on the phenological stage impacting on its growth phenology. This idea should be tested by combining retrospective measures of radial growth and wood anatomy, and measuring proxies of gas-water exchange ($\delta^{13}C$, $\delta^{18}O$, $\delta^{2}H$) in xylem wood and water at inter- and intra-annual scales. These proxies should be compared with field measures of root depth. Further, dendrometer data could inform on facultative shifts between unimodal and bimodal growth patterns.

CRediT authorship contribution statement

Camarero J. Julio: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Abdoun Fatiha:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Ifticene-Habani Naima:** Writing – review & editing, Supervision, Software, Resources, Methodology, Investigation, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dendro.2025.126326.

Data Availability

Data will be made available on request.

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