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RESEARCH ARTICLE

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Tree-ring reconstruction of March-June precipitation from the Atlas cedar forest of Mount Takoucht, Béjaïa (northern Algeria)

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Abstract

Aim of study: A March-June precipitation has been reconstructed for the period 1830-2015 using Atlas cedar (*Cedrus atlantica* Manetti) tree-ring records.

Area of study: Atlas cedar forest of Mount Takoucht (Béjaïa, northern Algeria).

Materials and methods: Seasonal correlations were computed in order to identify the best period of the year for the climate reconstruction. The temporal stability of the tree-ring signal for precipitation was checked using the split-sample calibration-verification procedure. The reconstruction was performed using the transfer function method.

Main results: The reconstructed data revealed high interannual to decadal variation in late winter to early summer precipitation. Wet conditions dominated during the 1830s and 1840s and were followed by sustained dry conditions during the mid-19th century, which registered two of the most severe droughts (1858 and 1869) over the period of reconstruction. Relatively moderate climate conditions marked the late 19th and early 20th centuries. A gradual return towards drier conditions was observed from the 1920s and reached high frequencies of drought around mid-20th century. After an exceptional prolonged wet period of 24 years (1966-1989), the reconstruction registered its highest frequency in extreme dry/wet events: the decade 1993-2002 recorded the highest drought frequency of the reconstruction, with the third most severe dry event (1999), while the last years were marked by a clear shift toward wet conditions.

Research highlights: These findings provide relevant records on past climate variability in one of the rainiest areas in Algeria and constitute valuable knowledge for specific drought and wet periods monitoring in the region.

Keywords: Dendrochronology; climate reconstruction; *Cedrus atlantica*; Algeria.

Authors' contributions: Conceived the work: SS, DK and FB. Fieldwork: SS and FB. Dated the samples: SS and DK. Performed the statistical analyses: SS, DK and FB. Wrote the paper: SS. Supervised the work and obtained funding: EG. All authors revised critically the text and approved the final manuscript.

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Introduction

Water scarcity has become a major constraint to socio-economic development and a threat to livelihood in increasing parts of the world (Liu *et al.*, 2017). The Mediterranean Basin has been referenced as a major climate change hotspot for the coming decades. It is expected that locally, up to 40% of winter precipitation could be lost, setting strong limits on water resources that will constrain the ability of the region to develop and grow food, affecting millions of already water-stressed people and threatening the stability of this area (Tuel & Eltahir, 2020).

Continuous high-quality instrumental data series in North Africa start in the early 1900s, but the majority cover only the latter half of the twentieth century. Tree-ring records, however, allow for the development of quantitative and validated paleoclimate drought reconstructions to help understand climate variability on time scales beyond that of the instrumental data (Touchan *et al.*, 2008a).

Tree-ring based climate reconstructions for the western Mediterranean highlighted a substantial increase in drought occurrence and severity during the last decades (Touchan *et al.*, 2008a, 2008b, 2010). Very few reconstructions involved only tree-ring data from Algeria (Kherchouche *et al.*, 2012, 2013; Slimani, 2014; Touchan *et al.*, 2016). They showed similar overall trend to that reported for the western Mediterranean, but revealed some contrasting differences in temporal precipitation variability between the Saharan Atlas and the Tellian Atlas. For example, a very severe drought provoked one of the worst episodes of forest dieback in the Aurès region (Saharan Atlas) between late 1970s and early 1980s (Kherchouche *et al.*, 2012, 2013; Slimani *et al.*, 2014), while this period was reported as wet for the Djurdjura massif (Tellian Atlas) (Slimani, 2014). Hence, local reconstructions would be relevant to highlight climate specificities of each area in a vast country like Algeria, where rainfall gradients are so contrasted from east to west and from north to south (Taibi et al, 2013).

In the current study, late winter/early summer precipitation is reconstructed for the region of Béjaïa (northern Algeria) using tree-ring data from the Atlas cedar forest of Mount Takoucht, a massif facing the Gulf of Béjaïa, which is one of the wettest areas in Algeria (Nouaceur *et al.*, 2013). The choice of the study site was based on the fact that Atlas cedar is a long-lived (Lepoutre, 1964) and highly sensitive species to climate variability (Kherchouche *et al.*, 2012, 2013; Slimani *et al.*, 2014; Touchan *et al.*, 2017). To the best of our knowledge, this is the first long-term climate reconstruction for the Algerian coastal area. This paper reports an analysis of extreme dry and wet periods for the study area, with a particular focus on the frequency, the duration and the severity of drought, which are relevant elements to water resources planning.

Material and methods

Study area

The Atlas cedar forest of Takoucht (TAK) is located at about 27 km, as the crew flies, east to Béjaïa, northern Algeria (Fig. 1), in one of the rainiest areas of Algeria (Nouaceur *et al.*, 2013). The study area is comprised between the latitudes 36°31'10.7" N and 36°31'30.3" N and the longitudes 5°12'00.9" E and 5°12'50.0" E. The sampled trees are located over an altitudinal gradient ranging from 1,378 to 1,713 m, on steep slopes (> 60%) and with north to northwest-facing aspects. The soil is well-drained, with shallow to medium-deep and derived from limestone. Most of trees were cored on rocky conditions in order to maximize the climate signal recorded in tree rings. Mount Takoucht is characterized by a humid Mediterranean climate, with a wet and cool winter and a dry and warm summer. The dry season lasts three months, from June to the beginning of September. The annual mean temperature is 10 °C: the mean monthly maximum temperature is recorded in August (M = 19.2 °C) and the mean monthly minimum is registered in January

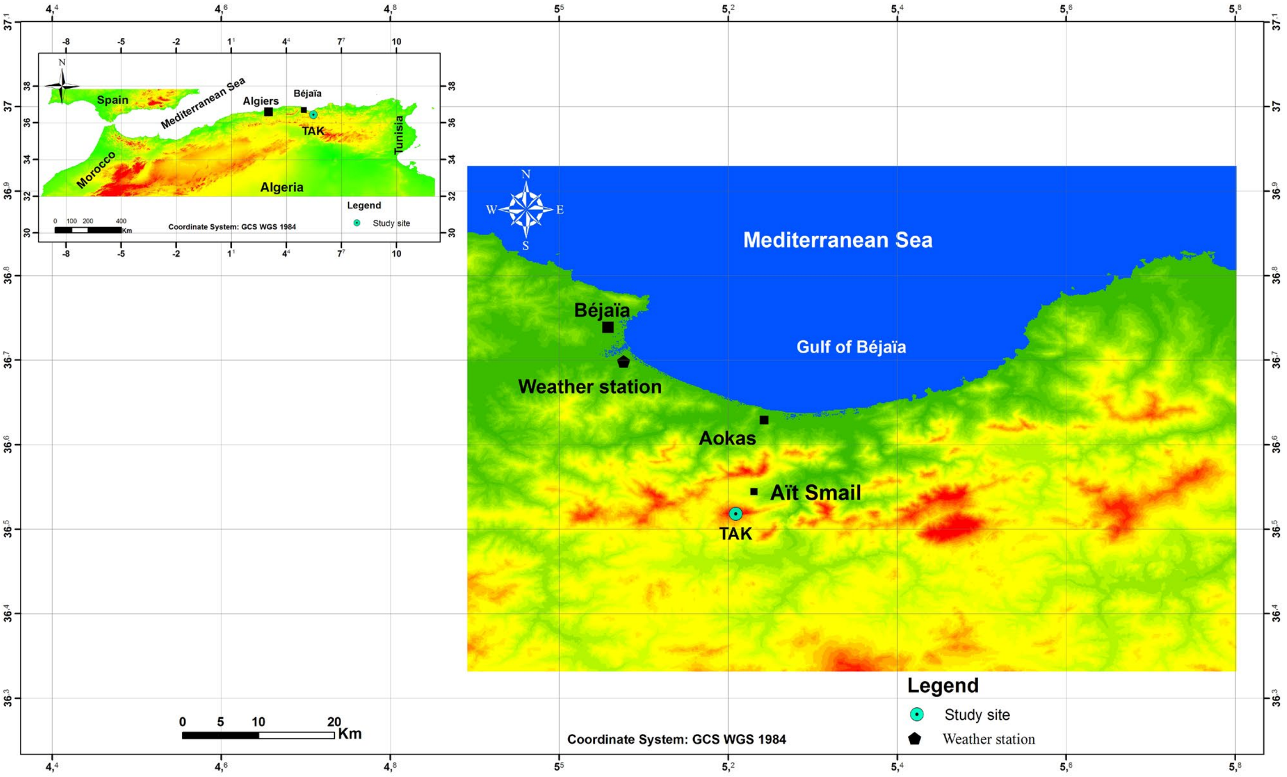

Figure 1. Location of the study area.

(m = 1.6 °C). The total annual precipitation is about 1410 mm and is characterized by high interannual variability. Snow falls from November and can, exceptionally, reach the beginning of May.

The north-facing slopes are well wooded and verdant. In contrast, the dry south-facing slopes are almost bare; trees are very rare and are only observed close to the mountaintop. The studied forest consists of pure stands of *Cedrus atlantica* with minor presence of *Quercus ilex*, *Juniperus oxycedrus, J. phoenicea, Taxus baccata, Acer opalus* subsp. *obtusatum*, and *A. campestre*. Main understorey vegetation consists of *Berberis hispanica, Prunus prostrata, Rhamnus alpina, Ampelodesmos mauritanicus, Inula montana, Teucrium kabylicum, T. chamaedrys, T. polium, Origanum glandulosum, Carlina involucrata, Helichrysum stoechas, Scabiosa columbaria, S. crenata, Trifolium campestre, Festuca atlantica, Dactylis glomerata, Poa bulbosa, Silene atlantica* and *S. choulettii.*

Tree-ring data

Twenty healthy Atlas cedar trees were cored in 2016 using an increment borer. Two cores from opposite sides were collected from each tree at breast height (1.30 m), where annual rings present lower risk of deformation (Delwaide & Filion, 2010). The samples were fine-sanded and crossdated using standard dendrochronological techniques (Stokes & Smiley, 1996). Ring widths were measured to the nearest 0.01 mm. The program COFECHA (Holmes, 1983) was used to confirm the accuracy of crossdating and measurements. The program ARSTAN (Cook, 1985) was used to standardize the tree-ring width series. Each series of measured ring width was fit with a cubic smoothing spline with a 50% frequency response at 67% of the series length in order to remove non-climatic growth trends possibly due to age, size, and the effects of stand dynamics (Cook & Briffa, 1990). The process involved dividing each year's ring width by the year's value of the fitted curve to give a dimensionless index with a mean of one (Fritts, 1976). Then, the detrended series were pre-whitened with low-order autoregressive models, based on the lowest Akaike's information criterion (AIC) value, in order to remove persistence not related to climatic variations. This procedure generates a series called "residual" index. The individual indices were then combined into a single master chronology using a bi-weight robust estimate of the mean (Cook, 1985). The expressed population signal (EPS) (Wigley *et al.*, 1984) was used to identify the period over which chronologies are well-enough replicated to capture the unknown common population tree-ring signal at a site. The analyses are based on the residual chronology with an EPS value continuously equal or above the 0.85 threshold.

Climate data

Many climate data sets were tested in the current study, including instrumental and gridded data. Only the instrumental records from the weather station of Béjaïa, located at about 24 km west to TAK (Fig. 1), provided high and significant correlations with the tree growth index of the studied Atlas cedar forest. They consisted of monthly total precipitation and average temperature covering the period 1978-2013.

Precipitation reconstruction

The program Seascorr (Meko *et al.*, 2011) was used to analyze the seasonal climate signal in tree-ring data. Correlations and partial correlations were computed for variable seasonal groupings between the tree-ring index as predictand and monthly total precipitation and temperature as predictors. The best seasonal grouping, showing strong significant and temporally stable correlations, was used for the climate reconstruction.

The reconstruction was performed using the transfer-function modeling using the tree-ring index as predictor and the climate data (precipitation in this study) as predictand (Fritts, 1976). A regression model and correlation statistics were used to assess the strength of the association between tree growth and the selected precipitation for reconstruction. The stability of the model was checked using the split-sample calibration-verification procedure (Snee, 1977), dividing the full period of available precipitation data into two subsets of equal length (1978-1995 and 1996-2013): a simple regression model is developed on the early subperiod (calibration) before it is used to estimate the precipitation over the late subperiod (verification), and vice-versa. The reduction of error statistic (RE) (Lorenz, 1956), which is particularly rigorous indicator of reconstruction reliability (Zhang *et al.*, 2019), was used to check the skill of the reconstruction compared with that of a simple model with the calibration-period mean of observed precipitation as the reconstruction: RE is calculated for the two estimations, including the observed and estimated precipitations of the verification subperiod and the mean precipitation of the calibration subperiod. This test is passed if the RE value is positive (Fritts, 1976). The regression model, calibrated over the full instrumental period (1978-2013), was cross-validated by the predicted error sum-of squares (PRESS) method (Weisberg, 1985 in Touchan *et al.* 2014). The PRESS method is equivalent to leave-one-out cross-validation, in which a model is validated iteratively by repeated calibration and validation, each time leaving one observation out of the calibration set and applying the model to predict the omitted observation. Estimated and predicted errors were also calculated for each year and used for assessing the model goodness-of-fit. An estimated error is the difference between an observed value and the value predicted by the model. The predicted error is the difference between an observed value and the predicted value calculated using the leave-one-out cross-validation procedure.

Once the final model was successfully validated, it was applied to reconstruct precipitation over the selected grouping period for the length of the tree-ring data. The reconstructed precipitations were plotted with a 10-year moving average in order to show high and mid-frequency time series variations.

Identification of extreme dry and wet events

Empirical thresholds for the dry and wet events were defined as 90% (181.4 mm) and 110% (221.7 mm) of the 1978-2013 mean observed March-June precipitation, respectively (Touchan *et al.*, 2005; Kherchouche *et al.*, 2012). Temporal changes in drought frequency were summarized in a moving window of 10 years. In addition, a histogram of severity index is provided. Drought severity is defined as the precipitation deficiency below the drought threshold (Touchan *et al.*, 2003; Kherchouche *et al.*, 2012; Slimani, 2014).

Results

Tree-ring data

A multicentury chronology was developed from our study area (Fig. S1 [suppl.]). The residual chronology showed good statistics for a climatic reconstruction (Table 1). The time span of the master chronology is 1568-2015 and the MSSL is greater than 200 years. The values of the standard deviation, skewness and kurtosis are 0.19, -0.14 and 0.93 respectively, and the Anderson-Darling normality test is significant (n = 186, α = 0.05). The mean correlation among individual radii is 0.29. The explained variance in the first principal component of the series over the common interval (1888-2015) accounts for 31% of the total variance. The EPS value is continuously above the 0.85 threshold from 1830 to 2015.

Precipitation reconstruction

Seasonal correlations are presented for the precipitation groupings of one, four, eight and twelve months (Fig. 2 and Table 2). March and May monthly precipitations are significantly and positively correlated (α = 0.05) with the tree-ring index (Fig. 2). May was identified as the single month of greatest precipitation influence on tree growth. Correlation with P increases with the increasing length of the averaging period, reaching its maximum for the period of four months ending in June (α = 0.01). Mean monthly temperature influence is positively significant (α = 0.05) for the single months of November preceding the growth year and February of the growth year and is negatively significant (α = 0.05) for May of the growth year. Table 2 lists the seasonal groupings of precipitation most highly correlated with TAK tree rings and highlights their temporal stability from early to late sub-period. The highest correlation is obtained from March to June, with the lowest difference from early to late period and the highest p-value for the test of null hypothesis.

Main results of the split-sample calibration and verification procedure between March-June precipitation and tree-ring index are reported in table 3. They show positive validation RE statistics and highly significant adjusted calibration and verification coefficients of determination. The final reconstruction model is based on the following linear regression equation:

$$Mar\text{-}Jun\ P = -85.8 + 292 * I$$

Where *Mar-Jun* P is the total monthly precipitation from March to June and *I* the growth index for the total period of calibration (1978-2013).

The model exhibited a highly significant adjusted calibration determination coefficient ($r^2 = 0.42$, $p = 0.000$, $n = 36$). In addition, the PRESS procedure generated a significant prediction coefficient ($r^2 = 0.37$).

Actual and estimated March-June precipitations are presented in Fig. 3. The Pearson correlation between the two precipitation series is 0.67 ($p = 0.000$, $n = 36$), the difference between their means over the 36 years of analysis is only 0.1 mm. No substantial difference was observed between estimated and predicted errors, which varied

Table 1. Residual chronology summary characteristics

Total chronology						Common interval		
Time span	MSSL[a]	SD[b]	SK[c]	KU[d]	EPS ≥ 0.85[e]	Time span	r[f]	% Ev PC1[g]
1568 –2015	212	0.19	-0.14	0.93*	1830	1888-2015	0.29	31

[a] mean sample segment length, [b] standard deviation, [c] Skewness, [d] Kurtosis, [e] the first year that the EPS (expressed population signal) is greater than 0.85, [f] mean correlation among all radii, [g] explained variance in the first principal component of the series over the common interval. * Anderson-Darling normality test (Anderson & Darling, 1954) accepted at α = 0.05.

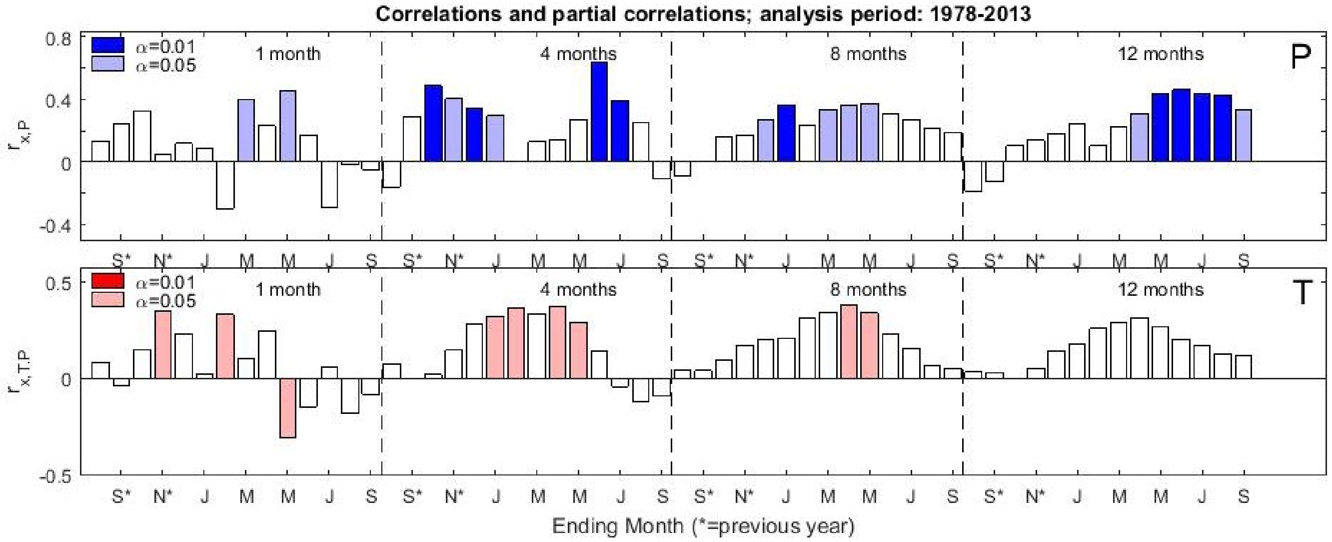

Figure 2. Correlations and partial correlations of TAK tree-ring series with seasonalized climate variables. (Top) Simple correlations with the primary climate variable, P (precipitation). (Bottom) Partial correlations of tree-ring index with secondary climate variable, T (temperature). Asterisk denotes year preceding tree-ring year.

in a relatively wide range of values. However, the scatter plot of residuals versus March-June fitted values (Fig. S2 [suppl.]) exhibits a random distribution and the residuals do not correlate with the estimated responses ($r = 0.00$, $p = 1.000$, $n = 36$).

Analysis of extreme dry and wet periods

The total March-June precipitation reconstruction for the period 1830-2015 and its 10-year moving average curve reveal high interannual to decadal variability (Fig. 4). The fixed empirical thresholds allowed determining 65 wet, 61 dry and 60 "normal" March-June periods. The wet events occurred with a mean interval of 2.9 years. The maximum interval without any wet event is 10 years (1954-1963). A total of 25 wet events had a duration of one year, 14 wet events had a duration of two years and four wet events had a duration of three years (1845-1847, 1888-1890, 1976-1978 and 2013-2015). The wettest reconstructed event was registered in 1862 (367.1 mm), while the wettest one for the instrumental data was 1985 (347.0 mm). Nonetheless, the reconstructed March-June precipitation for the year 1985 (296.6 mm) was also over the wet threshold. Major wettest decades occurred between the moving periods 1944-1953 and 1976-1985. The 61 March-June dry events were registered with a mean occurrence interval of 2.8 years. The maximum

Table 2. Temporal stability of the highest correlations between the precipitation and TAK tree rings from early to late sub-period. Full = 1978-2013, Early = 1978-1995, Late = 1996-2013

Season [a]		Correlation [b]			Sample size [c]		Test results [d]	
Months	length	Full	Early	Late	*N1*	*N2*	ΔZ	*p*
May	1	0.46	0.38	0.51	18	18	-0.1551	0.671
Mar-Jun	4	0.64	0.65	0.67	18	18	-0.0283	0.938
Oct*-May	8	0.37	0.63	0.28	18	18	0.4492	0.219
Jul*-Jun	12	0.46	0.68	0.40	18	18	0.4202	0.250

[a] Start and end months and number of months in season; asterisk denotes year preceding tree-ring year. [b] Pearson correlation of tree-ring index with precipitation as primary climate variable for full, early and late period. [c] *N1* and *N2* are the effectives sample sizes for the correlations computed on early and late sub-periods respectively. Effective sample size is fewer than the number of observations if both time series have positive lag-1 autocorrelation. Autocorrelation for the assessment computed on the full analysis period. Sample-size adjustment after Dawdy and Matalas (1964) *in* Meko et al. (2011). [d] The test statistics (ΔZ) is the difference between transformed correlations for early and late periods, following Panofsky and Brier (1968) and Snedecor and Cochran (1989) *in* Meko et al. (2011). The last column is the *p*-value for a test of null hypothesis that the population sample correlations for early and late periods are the same. A significant difference in sub-period correlations is indicated by a small *p* (*e.g.*, $p<0.05$).

Table 3. Split-sample calibration and verification statistics between March-June precipitation and tree growth.

Calibration period	Verification period	Adjusted r^2 calibration	r^2 Verification	*p*	*RE*
1978-1995	1996-2013	0.43	0.67	0.002	0.20
1996-2013	1978-1995	0.43	0.46	0.002	0.38

interval without dry events reached 24 years and was recorded between 1966 and 1989. A total of 29 dry events had a duration of one single year, 11 events had a duration of two years, two events had a duration of three years (1873-1875 and 1902-1904) and one event lasted four years (1956-1959). The driest March-June period was recorded in 1858 (54.1 mm). The driest event for the instrumental series was noted in 1994 (66.9 mm), which also was identified as a dry event in the reconstructed data (163.3 mm). Major driest decades were noted in the second half of the 19th century, in the mid-20th century and between the end of the 20th and the beginning of the 21st centuries.

It is worth mentioning that the frequency of extreme events reached its maximum during the last few decades: over the last 27 years (1989-2015), 11 events were wet, 11 were dry and only five (1991, 1995, 2001, 2004 and 2005) recorded a normal March-June precipitation. Moreover, throughout the whole period of reconstruction, the decade 1993-2002 registered the highest number of droughts (seven dry against one wet and two normal events), while the last decade (2006-2015) was the only one to record only extreme events, with seven wet and three dry (2006, 2009 and 2012) March-June periods.

A scan of Fig. 5 reveals that the first peaks in the frequency of droughts occurred around the mid-19th century. After a relatively low variability in late winter/early summer precipitation, an increase in drought occurrence was registered in the 1920s and mid-20th century, which was followed by 24 years (1966-1989) without any notable dry event. The highest frequencies were recorded over the last decades, between the end of the 20th and the beginning of the 21st centuries. This period also registered one of the three most severe droughts over the period of reconstruction (Fig. 6), which occurred in 1858, 1869 and 1999, with a March-June precipitation deficit of 127.3 mm, 94.0 mm and 93.1 mm respectively.

Discussion

Tree-ring data

The slight negative skew, the low excess kurtosis, and the results of the Anderson-Darling test (Table 1) justify the goodness of fit of the used tree-ring data with a normal distribution. The average correlation among all individual radii (0.29) and the explained variance in the first principal component of the series over the common interval (31%), which represent the strength of their common climatic signal (Touchan *et al.*, 2014), is the lowest registered from all the sites used for climate reconstruction in Algeria so far (Touchan *et al.*, 2008a, 2010, 2016, 2017; Kherchouche, 2012, 2013; Slimani, 2014). This reflects the moderate common growth signal among our sampled trees, which is mainly due to the relatively wet conditions of the study area. The mean sample segment length indicates that our chronology is suitable for investigating high and mid-frequency climate variability on interannual to decadal time-scales. Moreover, the EPS statistics shows that by the 1830s, individual chronologies are sufficiently well replicated to capture the population growth-signal.

Precipitation reconstruction

Fig. 2 highlights the importance of March-June precipitation as the most obvious controlling factor on the growth

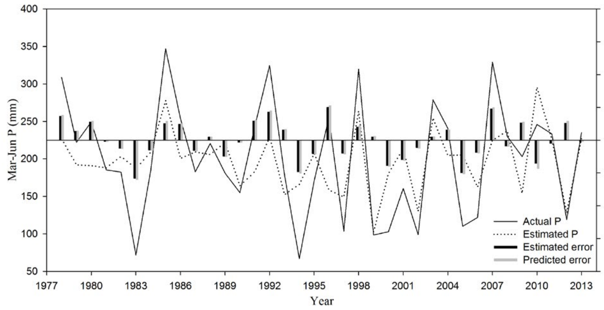

Figure 3. Actual and estimated March-June precipitations (P) for the period 1978-2013.

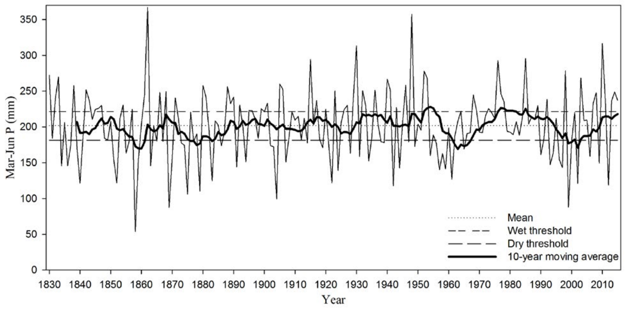

Figure 4. Reconstructed March-June precipitation P for the period 1830-2015.

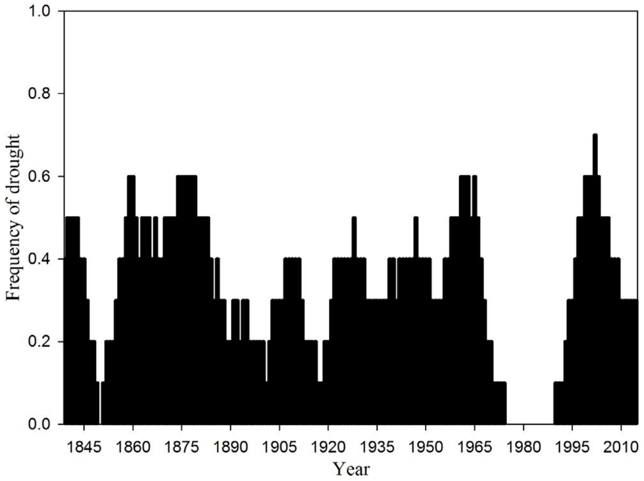

Figure 5. Frequency of drought events in 10-year windows.

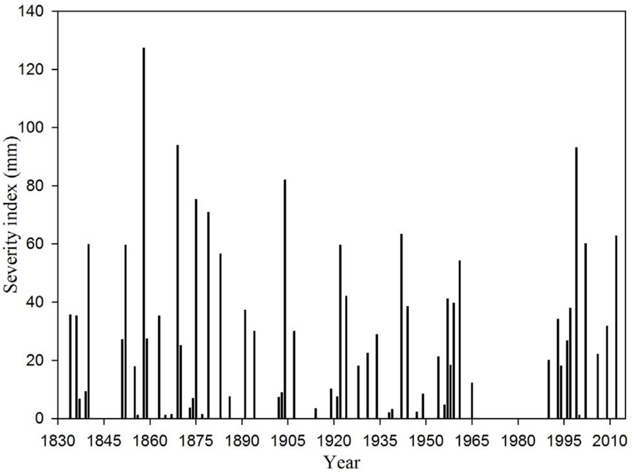

Figure 6. March-June severity index for the period 1830-2015.

of TAK Atlas cedar forest. The results also showed the importance of an increase in mean monthly temperature during the cold and rainy period. May is the only month to be significant with both monthly total precipitation (positively) and average temperature (negatively). This indicates that during the beginning of the hot period, an increase in mean temperature is efficiently attenuated by an increase in total precipitation. In contrast, a hot May associated with a rainfall deficit affects negatively tree growth. Negative impacts of rainfall deficit, especially during the growing season, are observed in many aspects of forest health including fine root biomass reduction, as a consequence of reduced transpiration and respiration rates, seedling recruitment, productivity and mortality of larger/mature trees, susceptibility to pathogen or insect attack, and vulnerability to damage from fire (Zhao & Running, 2010; Reichstein *et al.*, 2013 ; Brunner *et al.*, 2015).

Seascorr identified March-June precipitation as the most appropriate seasonal predictand for reconstruction (Table 2), which accounts for about one-fourth of the total annual rainfall. The highest p-value for the test of null hypothesis confirms the stability of the correlation from early to late period. These key months for precipitation influence on tree growth have also been identified for the eastern Mediterranean (Touchan *et al.*, 2003, 2005, 2007, 2014; Akkemik *et al.*, 2005, 2008; Griggs *et al.*, 2007; Köse *et al.*, 2011).

Calibration and verification statistics for the period 1978–2013 generated positive validation RE statistics, indicating a good level of predictive skill. Split-sample validation supports temporal stability of the tree-ring signal for precipitation but validated stronger on the second half of the reliable instrumental data (Table 3). This is due to the fact that the early period experienced lower precipitation variability than the late period: the reconstructed data exhibited seven extreme events (four wet and three dry) from 1978 to 1995 and 14 extreme events (seven wet and seven dry) from 1996 to 2013. In addition, the PRESS procedure showed a small drop from adjusted r^2 to predicted r^2, which suggests that the final model has not been overfitted. Moreover, the highly significant correlation between actual and estimated precipitations and their very low mean difference, as well as the fact that the residuals are not correlated with the predictand variable confirm the robustness of the used statistical model.

Analysis of extreme dry and wet periods

The 10-year moving average of the reconstruction reveals high interannual to decadal variation in March-June precipitation, which correspond to high and mid-frequency climate signals (Fig. 4). This trend is confirmed by the low mean intervals between two successive wet (2.9 years) or dry (2.8 years) March-June periods, which promote the occurrence of prolonged extreme events.

The reconstructed data is relatively equally distributed among wet, dry and normal events. It includes 86% of the wet events and all the dry events reported by Slimani (2014) for an October-June precipitation reconstruction from the Atlas cedar forests of the Djurdjura massif for the period 1898-2011. Less common extreme events (29% of the wet and 61% of the dry years) have been observed between our reconstruction and that reported by Slimani (2014) in the Aurès region. It is noteworthy that on their common period (1830-2009), all the shared wet events between these two reconstructions occurred during the last four decades and the best synchronicity in dry events was registered during the last decade. This reflects the substantial increase in the common growth response between these distant forests to macroclimatic conditions from the middle part of the 20th century. Similar results have been noted between the Atlas cedar forests of the Tellian Atlas and the Saharan Atlas (Slimani, 2014). Stronger growth-climate relationships due to climatic restrictions have also been reported by many authors for the European forests, from the Mediterranean to Siberia

(Andreu *et al.*, 2007; Shestakova *et al.*, 2016; Del Rio *et al.*, 2021).

The driest single March-June period was recorded in 1858, while all data from previous reconstructions in Algeria reported the driest event in 2002 (Touchan *et al.*, 2008a, 2010, 2016, 2017; Kherchouche *et al.*, 2012, 2013; Slimani, 2014). In our reconstruction, the 2002 March-June precipitation is only the ninth-driest year. Actually, this year has been one of the rainiest in the instrumental data, with total annual precipitation of 1021.5 mm, while the average annual precipitation is 781.1 mm. Despite this, the cored trees produced a narrow ring. This is due to the very irregular precipitation in 2002, with a severe deficit in spring and a rainy summer in form of heavy storms. Likewise, the year 2012 registered a total annual precipitation over the mean (895.6 mm) but also generated a narrow ring. Examination of the daily data also showed a very high precipitation irregularity during this year, with a very high number of stormy days (37), and revealed that 61% of the winter-spring precipitation fell in February (320 mm), for which the monthly precipitation exceeded the average by 350%. Moreover, during that year, from December to June, only April did not register a rainfall deficit. These results highlight that rainy years characterized by very high irregular distribution and spring precipitation deficit can result in agricultural droughts, because too much water is not efficient as it falls outside the growing season or in form of heavy rain and, consequently, is not used by the plants (Mannocchi *et al.*, 2004).

The first two decades of the reconstruction were dominated by wet events. Half of the years from 1830 to 1847 registered a March-June precipitation above the wet threshold (1830, 1832-1833, 1838, 1842-1843 and 1845-1847). Touchan *et al.* (2008b) also reported 1833 as a wet year for the northwestern Tunisia. Nicault *et al.* (2008) noted that the nineteenth century in the Mediterranean region was dominated by wet conditions although with a relatively dry period around 1860. Emerit (1972) reported that the popular uprise led by shaykh El-Mokrani and shaykh Aheddad in 1871 in the region of Kabylie was mainly due to the miserable situation of the population, which, at the end of the Second French Empire, suffered various calamities such as epizootics, locust outbreak, disease outbreaks, drought, poor harvest and severe famine. Indeed, during the two decades preceding this revolt (1851-1870), our reconstruction exhibited 11 events of drought, among which four events lasted two years (1851-1852, 1855-1856, 1858-1859 and 1869-1870). Touchan et al (2008a) reported the year 1867 as the second single driest event since the middle of the 15th century in northwestern Africa. Emerit (1961) noted that the biggest economic crisis in Algeria in that period has been that of 1867-1868, during which a part of the country was subjected to a dreadful famine. The author reported that in 1867 the drought was so severe that seeds could not germinate and herds died in droves from lack of food, and, enfeebled by privation, the population became an easy prey to typhus and cholera. The same information have been reported by Kitouni (2013), who added that 500,000 persons, representing about a fifth of the total Algerian population at that time, died of hunger and hunger-related diseases. Nonetheless, it must be mentioned that in the reconstructed precipitation, 1867 was identified as a dry event, but does not figure among the driest ones. In this regard, Emerit (1972) pointed out that the revolt broke out in the regions less affected by starvation. Indeed, receiving higher rainfall than the interior of the country, the Kabylie region suffered less from famine (Emerit, 1961; Kitouni, 2013). It is noteworthy that in our reconstruction this year is followed by a wet event. Similar result was reported by Touchan *et al.* (2008b) in Tunisia where a severe drought occurred in 1867 and was followed by the single wettest year (1868) registered during the period 1771–2002.

From 1873 to 1880, the reconstructed data contained five dry events (1873, 1874, 1875, 1877 and 1879) and only two normal March-June precipitations (1876 and 1878). This result is consistent with those mentioned by Kherchouche *et al.* (2012, 2013) and Slimani (2014) who noted sustained dry conditions for the Aurès region during this period. Boudy (1950) in Abdessemed (1981) noted that an exceptional drought could have occurred between 1875 and 1880, which could have destroyed many stands of Atlas cedar in the Aurès region. Dieback of entire stands of Atlas cedar, associated to severe drought and/or severe winters, especially those of 1879 and 1880, has also been reported by Lapie (1909, 1928) for the Aurès and Kabylie regions. In northwestern Africa, Touchan *et al.* (2008a) reported a six-year drought from 1876 to 1881, where every consecutive year was below the long-term reconstructed Palmer Drought Severity Index (PDSI) mean. The year 1879 has also been marked by a May-July rainfall deficit in Cyprus (Touchan *et al.*, 2014). In Ankara (Turkey), Kuniholm (1990) reported that a severe drought event occurred during the period 1873-1874, which resulted in the death of nearly a third of the human population as well as large number of herd animals.

This period of drought ended with a wet event that lasted two years (1880-1881) and the following four decades, from the 1880s to 1910s, were dominated by wet conditions, especially during the period 1888-1901, which did not record any dry event and where eight out of the fourteen years recorded a wet March-June period.

A return to dry conditions started in the 1920s and reached high drought frequencies around the mid-20th century. Similar results were reported for the Aurès region by Kherchouche *et al.* (2012, 2013) and Slimani (2014) and for the northwestern Africa by Touchan *et al.* (2008a). The last dry event recorded in the 1920s in our reconstruction occurred in 1928. Touchan *et al.* (2014)

mentioned this event as the driest single year during the last six centuries in Cyprus. This period was followed by a two-year wet March-June period ending with the fourth wettest event of the reconstructed data (1930). Touchan *et al.* (2005) reported similar results in the spring/summer precipitation reconstructions for the eastern Mediterranean. Half of the years over the period 1938-1949 registered dry events (1938, 1939, 1942, 1944, 1947 and 1949). Similar trend was reported in Algeria by Kherchouche *et al.* (2012, 2013) and Slimani (2014). OSS (2008) mentioned the droughts of the decade 1940s, during which several weather stations recorded until eight successive dry years, as the worst of the 20th century in Algeria. According to Tinthoin (1946), the period 1938-1945 was marked by low crop yields and herds suffered heavy losses because of drought, which became more and more pronounced, especially between 1942 and 1945. In his literature, Camus (1947, 1948) also wrote about the 1940s as a period of continuing concern with respect to drought, plague, and famine. Touchan *et al.* (2008a) have also noted these substantial and sustained dry conditions during this decade over the northwestern Africa. Et-tobi *et al.* (2009) reported that during this period a severe drought caused one of the worst forest dieback episodes in Morocco. In southern Turkey, Touchan *et al.* (2003) noted the lowest five-year spring mean precipitation in the instrumental record (1931-1998) during the period 1941-1945. In Cyprus, Touchan *et al.* (2014) mentioned the year 1949 as the driest in the instrumental data for the period 1917-2010.

In our reconstruction, the longest period of drought lasted four years and occurred between 1956 and 1959. However, these events are not among the most severe ones. Nonetheless, Meddour-Sahar *et al.* (2008), listed the years 1956, 1957 and 1958 among the worst Algerian forest fires statistics.

No dry event occurred throughout the period 1966-1989, during which was recorded one of the wettest 10-year reconstructed periods (1976-1985) and one of the three wet periods that lasted three years (1976-1978). Similar result has been reported by Slimani (2014) in the massif of Djurdjura over the period 1962-1993, while one of the worst dry events recorded in the Aurès region occurred between late 1970s and early 1980s and resulted in a severe episode of forest dieback (Kherchouche *et al.*, 2012, 2013; Slimani, 2014). Kettab *et al.* (2004) reported that on a temporal scale, the Algerian coastal area experienced a wet period from 1954 to 1986. In Cyprus, Touchan *et al.* (2014) noted that the period 1967-1976 was the wettest reconstructed decade over the six last centuries.

After the mentioned extended wet period, our study area experienced its maximum precipitation variability over the last decades, which were marked by two main contrasting intervals. The first period is the decade 1993-2002, which recorded the maximum number of dry events and contained the third lowest late winter/early summer precipitation (1999). This shift towards drier conditions from the 1990s to early 2000s has been mentioned in Algeria, for the Kabylie and Aurès regions (Kherchouche *et al.*, 2012, 2013; Slimani, 2014, Slimani *et al.*, 2014), in Tunisia (Touchan *et al.*, 2008b), in Morocco (Esper *et al.*, 2007; Linares *et al.*, 2011) and over northwestern Africa (Touchan *et al.*, 2008a, 2010), and was directly associated to the last forest dieback episode that occurred in the Mediterranean Bassin (Allen *et al.*, 2010). In addition, Meddour-Sahar *et al.* (2008) reported a substantial increase in fire occurrence in Algeria between 1992 and 2000. During this period, seven out of nine years, which were registered over the two periods of successive years 1992-1994 and 1997-2000, largely surpassed the yearly average fire frequency: among these years, 1993, 1994, 1997, 1999 and 2000 have been identified as dry events in our reconstruction. Moreover, Touchan et al (2008a) pointed out that the 1999-2002 droughts in North Africa appear by several metrics to perhaps be the worst since at least the middle of the 15th century. However, a scan of Figs. 5 and 6 reveals that in our study area this period is marked by the highest frequency of drought, while the most severe events occurred in the mid-19th century. After this last dry interval, the last decade of the reconstruction (2006-2015), registered the maximum frequency in wet events and contained the third wettest March-June period (2010). In their investigation on the evolution of temperatures and rainfall over the Algerian coastline, Nouaceur *et al.* (2013) noticed that after a very dry period of about 15 years, wet and hot conditions prevailed during the decade 2003-2012, which was characterized by heavy rainfall involving severe storms. In this respect, Morsli & Habi (2012) noted that floods in Algeria are rarely due to large-scale weather disturbances and are mainly caused by localized and short-lived but devastating torrential rainstorms. During the last decades, such flooding episodes, like those of Bab El Oued (Algiers) in 2001 and of Ghardaïa in 2008, caused considerable material damages and killed 772 and 43 people respectively (Nouri *et al.*, 2016).

Conclusion

This study presents the first long-term climate reconstruction using tree-ring data for the region of Béjaïa, which is one of the wettest areas in Algeria. Annual growth rings from the Atlas cedar forest of Mount Takoucht contained valuable records in late winter to early summer precipitation.

The reconstructed data revealed high interannual to decadal variation in March-June precipitation and the highest variability marked the last decades. The most severe single drought and the wettest event were registered during the same 10-year period, in 1858 and 1862 respectively. The longest wet event during the past 186 years lasted three years and occurred three times (1845-1847, 1888-1890 and 1976-1978). The most prolonged drought lasted four year and was recorded only once (1956-1959). The reconstructed data exhibited contrasting alternating wet and dry periods. Wet conditions prevailed over the 1830s and 1840s, and were followed by sustained dry conditions from the 1850s to 1870s, during which were registered two of the most severe droughts (1858 and 1869). After relatively moderate and stable climate conditions from the late 19th to the early 20th centuries, the decade 1920s marked a return to drier conditions, which reached high frequencies of drought around mid-20th century. This period was followed by the most prolonged interval (1966-1989) without any notable dry event. The last few decades registered the highest frequencies in extreme late winter/early summer precipitations. The highest drought frequency was reached during the decade 1993-2002. In contrast, the last decade (2006-2015) marked a clear shift to wet conditions.

Our findings provide relevant information on wet events and on the frequency, duration and severity of drought in the region of Béjaïa during the last 186 years. This constitutes reliable elements for water resource management within the framework of the current climate change.

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