

Tree ring growth of *Cedrus atlantica* Manetti under climate conditions throughout Moroccan Middle Atlas mountainsCrescimento de anéis de crescimento de árvores de *Cedrus atlantica* Manetti em condições climáticas na região montanhosa em todo o Médio Atlas marroquinoRachid Ilmen^{1*}, Abdelhakim Sabir², Mohamed Benzyane³ and M'Hamed Hachmi⁴**Abstract**

Under the background of climate change, precipitation and temperature variability have occurred widely and frequently in Morocco in recent years. However, relatively few studies investigated this phenomenon. Using tree rings to study climate variability has some advantages such as accurate dating, strong continuity and high resolution. In this study, 80 tree cores from 40 trees of *Cedrus atlantica* M. were collected from two forest sites Ain Khahla (Site I) and Bikrit (Site II) located in the Middle Atlas region of Morocco. Analysis of increment cores showed that trees in both forest stands were between 85-349 years and between 268-644 years old in Site I and Site II, respectively. Mean tree ring width was greater (1.570 mm/year) in the first site than in the second one (0.730 mm/year). Series intercorrelation was 0.268 for Ain Khahla and 0.355 for Bikrit. Values of Expressed Population Signals (EPS) obtained were higher than 0.940 in both sites. The high mean sensitivity obtained, superior to 0.2, indicates a high inter-annual variability in ring widths and that chronology was sensitive to yearly environmental change. A positive precipitation effect was found in March for site I. High autumn and spring temperatures in both the previous and current year generally had a negative impact on tree-ring width during the growing season only in Ain Khahla. It is suggested that these chronologies have a high potential for future dendroclimatic studies. However, there is a need for larger sample sizes and further extension of these chronologies into the past.

Keywords: *Cedrus atlantica*, Climate, Growth, Morocco, Tree ring, Width, Chronology

Resumo

Sob o cenário das alterações climáticas, tem ocorrido uma variabilidade da precipitação e da temperatura ampla e freqüente no Marrocos, nos últimos anos. No entanto, relativamente poucos estudos investigaram esse fenômeno. O uso dos anéis de crescimento de árvores para estudar a variabilidade climática apresenta vantagens como a datação precisa, forte continuidade e alta resolução. Neste estudo, 80 amostras do lenho de 40 árvores de *Cedrus atlantica* M. foram coletadas em dois sítios das florestas de Ain Khahla (Sítio I) e Bikrit (Sítio II) localizados na região do Médio Atlas, Marrocos. A análise das amostras do lenho das árvores mostrou que as árvores dos dois povoamentos florestais tinham de 85-349 anos e 268-644 anos de idade nos Sítios I e II, respectivamente. A média da largura dos anéis de crescimento foi maior (1.570 mm/ano), no primeiro Sítio em relação ao segundo (0.730 mm/ano). O valor da intercorrelação das séries foi de 0,268 para Ain Khahla e de 0.355 para Bikrit. Os valores obtidos dos Sinais Expressivos da População (EPS) foram superiores a 0.940 nos dois sítios. A alta sensibilidade média obtida superior a 0.2 indica uma alta variabilidade inter-anual da largura dos anéis de crescimento e a cronologia foi sensível à mudança ambiental anual. O efeito positivo da precipitação foi encontrado em março para o Sítio I. As altas temperaturas de outono e de primavera no ano anterior e atual tiveram, geralmente, um impacto negativo na largura dos anéis de crescimento durante a estação de crescimento apenas em Ain Khahla. Sugere-se que estas cronologias de anéis de crescimento têm um elevado potencial para futuros estudos dendroclimáticos. No entanto, há necessidade de aumentar o número de amostras e a extensão das cronologias em relação ao passado.

Palavras-chave: *Cedrus atlantica*, Clima, Crescimento, Marrocos, Anéis de crescimento, Largura, Cronologia

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INTRODUCTION

In the last century, our planet has experienced a climatic change that is partly a result of natural variations in the Earth's systems and partly attributed to Man's alteration of the geosphere, biosphere and atmosphere (IPCC, 2001). Trees in temperate zones of the Earth offer an excellent opportunity for developing networks of high-resolution proxy data. In areas where the annual growth is limited by the amplitude in warm season temperature a new layer of wood is formed each year, a "tree ring", which has specific physical and chemical characteristics, for example, ring width; maximum density or isotopic composition and by measuring such characteristics in consecutive rings it is possible to produce annually resolved time series that are correlated to the mean temperature of the growing season (SCHWEINGRUBER, 1988). Wood anatomical features measured in tree rings may offer opportunities for obtaining environmental information (BEECKMAN, 1993). In many studies growth rate is the only considered parameter since ring widths are usually easy to measure and to interpret (BLASING; FRITTS, 1976; SZEICZ, 1997). Carefully replicated measurement series from many trees in an area can then be averaged, calendar year by calendar year, to construct mean time series (a "chronology") that can be used for climate reconstruction and that will extend into the past for as long as there is sufficient material.

Dendrochronology is the science that uses tree rings dated to their exact year of formation to analyze temporal and spatial patterns of processes in the physical and cultural sciences (GRISSINOMAYER, 2007). There are many such natural archives of paleoclimatic information, including ocean and lake sediments, peat bogs and ice cores, but none have the two great advantages of tree rings. First: the exact dating of each ring provides perfect annual resolution. Second: each part of the chronology is represented by several overlapping trees, so it is possible to define the variability of a measurement as well as the average value, allowing confidence limits to be calculated. Trees are also widespread, which therefore facilitates the examination of climate variations in the past, which may be more decisive for predicting the consequences of future climate change (MCCARROLL; LOADER, 2004). Cedar mountain species occupy mainly surfaces of unequal importance and spontaneously form three distinct geographical units: Asia, Himalaya and North Af-

rica. The first block is divided into two parts; each occupied by a particular species: *Cedrus libani* B. (1700 ha) in Lebanon, several hundred hectares in Syria and over 160,000 ha in Turkey, Taurus and Amanus between 1500 and 2000 m; but *Cedrus brevifolia* H. is found on the island of Cyprus in Paphos forest. The second block with *Cedrus deodara* L. is massive in Afghanistan and India on the north-western Himalayas between 1350 and 3500 m. The third block contains *Cedrus atlantica* M. and includes the Algerian Atlas (40,000 ha), Atlas of Morocco (140,000 ha) and Rif (20,000 ha) (M'HIRIT, 1993). Morocco is lying within the influence zone of the Atlantic Ocean, the Mediterranean Sea and the Sahara. Indeed, relatively few studies, however, investigate Moroccan precipitation variability and its links to the large-scale atmospheric circulation in particular. Few studies were devoted to the influence of the North Atlantic Oscillation (NAO) and El Niño-Southern Oscillation (ENSO) on rainfall in Morocco (LAMB et al., 1997; WARD et al., 1999). Parts of Morocco have suffered from series of dry years since the late 1970s including the winter of 1999-2000. Hurrell; Van Loon (1997) assigned some of the reduction in precipitation to the NAO extremes in the 1980s and 1990s. There was an increase in the relative variability of annual rainfall south of the Atlas Mountains for two periods; 1931-60 and 1961-90 according to Hulme (1992). It is not clear if this is just part of natural variability or an indication of climate change and whether this change is anthropogenic or not. Completely semi-arid regions, particularly in southern and eastern Morocco are confronted with a high year-to-year precipitation variability and are therefore highly sensitive to climate change (BULLOCK; LE HOUEROU, 1996). During the period 1980-1985, the rivers registered between 50% and 90% decreases from their respective long-term mean flow (CHBOUKI, 1992) and many natural lakes dried up completely (BELKHEIRI et al., 1987). In recent times, 1999-2002 droughts in North Africa seem to have been the worst since at least the middle of the fifteenth century (TOUCHAN et al., 2008a). Therefore, understanding reasons for precipitation variability is a decisive key to manage future problems with natural ecosystems. Unfortunately cedar is in decline during the last decades, the reduction of its area has been subject of great concern in Morocco since the early 1990's; the last study conducted in Middle Atlas treats the cedar degradation causes (MOKRIM, 2009). Furthermore, the duration of the dry season changes

inversely with the corresponding growth index (ET-TOBI et al., 2009). Hence the necessity to undertake climate studies about cedar tree rings in extreme conditions where cedar will be more sensitive to climate change. The species is described to be highly suitable for such an analysis because of its precipitation sensitivity and long life span. In order to update some of the existing records and to further increase the sample replication particularly of younger trees, new samplings and re-samplings of cedar sites in the Middle Atlas were performed in year 2012. In this paper we study the potential response of cedar ring width to climatic factors, particularly temperature and precipitation.

MATERIALS AND METHODS

Cedar tree in Morocco

The Moroccan mountains are, from north to south, the Rif, the Middle Atlas, the High Atlas and the Anti-Atlas. They are oriented along two axes, a west-east one in the Rif area and a south-west north-east one in the Atlas zone, with a maximum altitude of respectively 2450 and 4200 m. As a result, various potential genera of forest trees could be used in dendroclimatic studies such as *Cedrus*, *Abies*, *Pinus*, *Quercus*, *Tetraclinis*, *Juniperus* and *Cupressus*. *Cedrus* grows from about 1300 to 2600 m. Atlas cedar is mainly observed in Morocco at the Mountain-Mediterranean and Oro-Mediterranean levels but it may also be observed at the Upper-Mediterranean and Supra-Mediterranean levels (BENABID, 1982). Its optimum corresponds to the Mountain-Mediterranean level (ACHHAL et al., 1980). Additionally, Ce-

dar has a relatively wide tolerance to climate and soil type. The Middle Atlas in northern Morocco is home of about 80% of the Atlas cedar forest. This species, mixed with several evergreen forest types such as *Quercus ilex*, *Juniperus oxycedrus*, deciduous trees and shrub species, has an important socioeconomic value.

Choice and study sites description

We conducted our research study in the Middle Atlas area which is characterized by a high biodiversity of flora and fauna, suitable for scientific research and special studies. This area is characterized by a specific climate in the region. Indeed, the west façade, Taza and Azrou is under influences from the Atlantic Ocean; its annual rainfall is about 1000 mm. The eastern valleys are much drier and characterized by increasing aridity. Middle Atlas generally experiences winters characterized by a low temperature, rainfall and snow, high above 2000-2500 m, in December and January (LECOMPTE, 1986). These conditions of temperature and rainfall are favorable to the development of vegetation belts. The study area has important cedar forests: Tamjilt, Meghraoua, Berkine, Taffert, Bni Souhane, Immouzzar Marmoucha, El Aderj, Sidi M'Guild, Azrou, Ain Khahla, Bikrit, Scnoual, Itzer, Ajdir, Kcrouchen, Jbd Aoua Sud, Ait Youssi Amekla, Aghbalou Larbi, Guigou and Ait Nokra. In the context of this prospective study we choose two cedar forests: Ain Khahla and Bikrit, denoted as Site I and Site II, respectively, as shown in Figure 1.

For both studied sites, the description data was provided from field measurements and are presented in Table 1.

Table 1. Geographic, ecological, dendro-metric and climate information of the two sampling sites.
Tabela 1. Informação geográfica, ecológica, dendro-métrica e climática dos dois sítios de amostragem.

Description	Site I	Site II
Latitude (N)	33°15'090"	33°01'031"
Longitude (W)	5°14'027"	5°14'729"
Elevation (m)	1900	2078
Slope (°)	40	45
Aspect	SE	SE
Average DBH of trees (cm)	305.85	407.15
Average height of trees (m)	20.775	17.675
Overstory	<i>Cedrus atlantica</i> <i>Quercus rotundifolia</i>	<i>Cedrus atlantica</i>
Understory	<i>Pistacia lentiscus</i> <i>Cistus monspeliensis</i>	<i>Genista pseudopilosa</i> <i>Dasypyrum hordeaceum</i> <i>Helianthemum croceum</i>
Bedrock	Dolomitic limestone	Quaternary bands of basalt
Mean distance between trees (m)	11	16
Soil depth (m)	2-5	2-6
Bioclimate	Subhumid	Subhumid

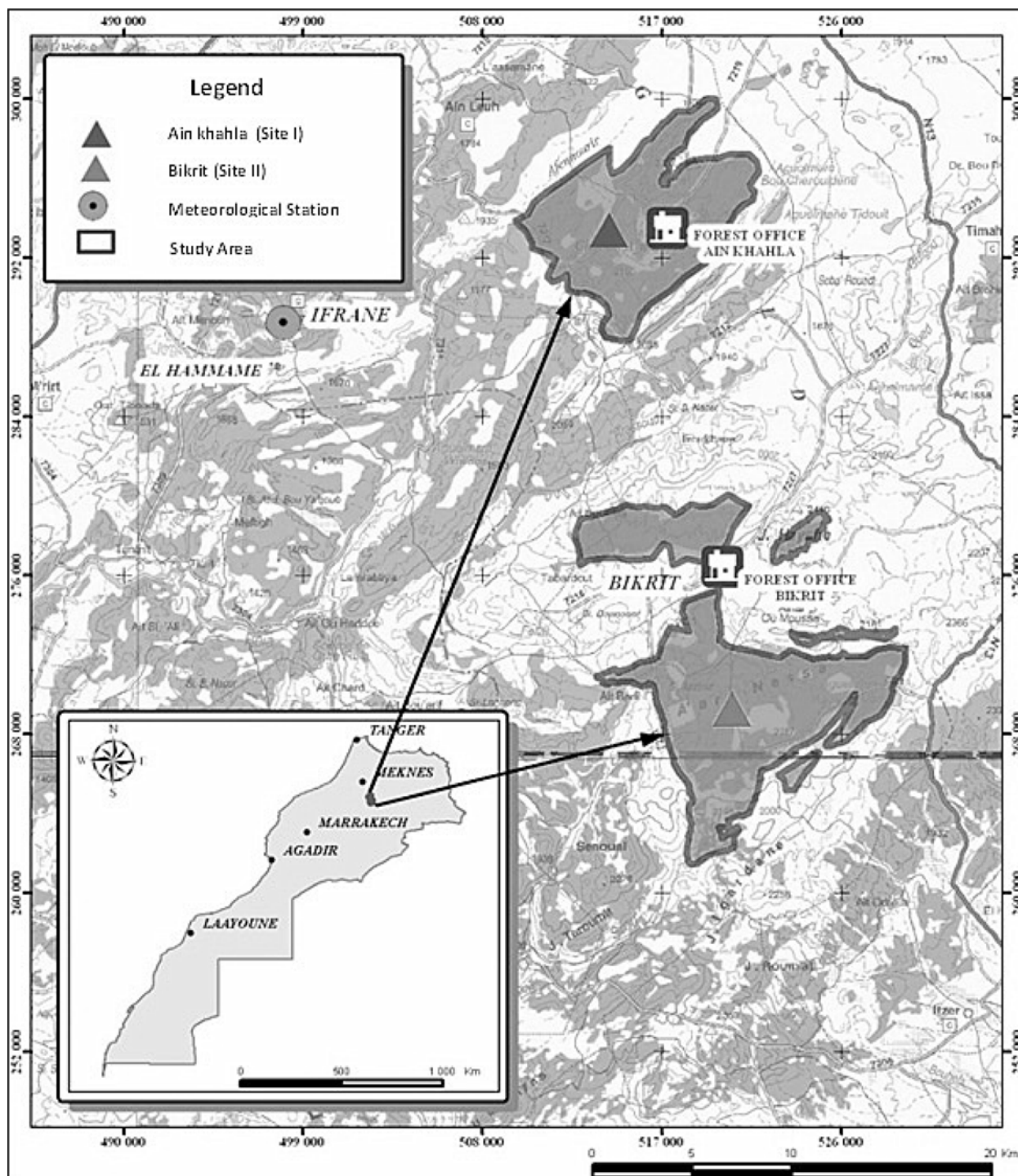


Figure 1. Location map of study sites and meteorological station.
Figura 1. Mapa de localização dos sítios de estudo e da estação meteorológica.

In Ain Khahla forest, understory is scarce because of dominant trees shadow. In both sites, *Cedrus atlantica* is the dominant tree species as shown in Figure 2 and Figure 3. The ecological conditions, however, differ considerably.

Sampling and procedure

During field sampling, we have to respect the principle of site selection which states that sites useful to dendrochronology can be identified and selected based on criteria that will produce tree-

ring series sensitive to the environmental variable being examined. Therefore, trees with major defects such as multiple stems, heavy insect damages or severe scarring were excluded. For ring width analysis a sample of two 5 mm cores/tree was taken at breast height (1.3 m) in opposite directions and perpendicular to slope during the year 2012. The cores were numbered and placed in special tubes in order to avoid mixture with other samples especially in case they were broken. The samples were taken using a Pressler in-



Figure 2. Ain Khahla forest.
Figura 2. Floresta de Ain Khahla.



Figure 3. Bikrit forest.
Figura 3. Floresta de Bikrit.

crement borer from each of the 20 trees/site. The two sample lots were taken separately in order to avoid error sources and problems caused by false or absent rings. According to Speer (2010) about 20 trees (two cores/tree) at each site or stand, can average out individual tree variability; while Fritts (1976) suggested 12 trees (two cores/tree). In general, obtaining numerous trees from one site and perhaps several sites in a region ensures that the amount of “noise” is minimized.

Proxy measurement

Each core was mounted and sanded following standard dendrochronological procedures; cores were air dried for 8 days and then placed in grooved wooden mounts with tracheids aligned vertically to give cross-sectional surface. To make core surfaces smooth, the samples were polished using a rotary electric belt sander with progressively finer grades of sandpaper from 60 to 320 grits. Annual radial growth was measured with a precision of 0.01 mm, using a measurement table for assessment of tree ring series called Lintab^{TM6} linked with Time Series Analysis Program TSAP-Win (RINNTECH, 2003), available in the Laboratory of Forest Products Technology of the National School of Forest Engineers in Salé, Morocco.

Statistical treatment

In the following section, we will present different parameters and the statistical softwares used in the present study:

Dendrochronological parameters

The time series were visually and statistically cross-dated using skeleton plot to obtain mean tree ring series for each cedar tree and to find similarities in the growth pattern. Some param-

eters are used by Schmidt (1987) such as Cross Date Index, (CDI) which calculates a date index for possible series matches and uses the Gleichläufigkeit value (Glk%) and T-Values (TV) to determine the quality of the series match (BAILLIE; PILCHER, 1973). Values of CDI superior to 10 were considered as being significant (RINNTECH, 2003). The T-Value-Baillie-Pilcher (TVBP) was also used.

Computer programs

According to Fritts (1976), certain statistics provide an objective quantitative base for evaluating the dendrochronological potential of a tree ring chronology. These statistics were obtained by running the programs COFECHA and ARSTAN. In addition, DENDROCLIM 2002 software allows studying tree ring-climate relationship.

Program COFECHA

The accuracy of crossdating was verified by using the computer program COFECHA, version 6.06. This software was used for controlling cross-matching quality of ring width series and to identify sections with sample asynchrony and areas of error.

Program ARSTAN

The ARSTAN program was used to remove age trends in ring width data and to build site chronology. The raw data of tree ring width were standardized using a three-step process: First: a negative exponential function was fitted with raw tree ring data; Second: a cubic smoothing spline with a 50% frequency cut off at 50 years was used to retain the high-frequency variability of radial growth; and Third: the mean chronology was built using a robust mean in order to reduce the

influence of negative or positive extreme values (COOK; HOLMES, 1986). Moreover, the signal strength in ring width chronology was tested using Expressed Population Signal (EPS) which is a measure of the common variability in a chronology and depends upon sample depth (WIGLEY et al., 1984). Only those series with a high common signal ($EPS \geq 0.85$) were included in the analysis.

Program DENDROCLIM 2002

The series were averaged to create total ring width chronologies for each site. Those chronologies were compared with climatic data to assess the impact of changes. The software package DENDROCLIM 2002 (BIONDI; WAIKUL, 2004) was used for the analysis using bootstrapped confidence intervals to estimate the significance of both correlation and response function coefficients and testing their significance at the 0.05 level (GUIOT, 1991). Analysis was performed using 12 monthly climatic data: monthly mean temperature and total monthly precipitation of the previous year and that of the current year were used as predictor variables to determine the significance of their effects on concurrent ring growth. In this calculation, the period lasts from May of the previous year to April of the current year.

RESULTS AND DISCUSSION

Growth dynamics

The mean tree ring width chronology of *Cedrus atlantica* at this Site I as presented in Figure 4 was elaborated by using 37 relative series taken from 20 dominant sample trees. Three cores were rejected due to bad quality. The chronology length is 349 years (time span 1663-2011) with a mean tree ring width of 1.570 mm (standard deviation ± 0.283). The cedar chronology shows cyclic

fluctuations during the entire period of time. The lowest radial growth reached was in the year 1698 (0.22 mm), while the maximal radial growth occurred in the years 1780 (5.75 mm) and 1781 (6.04 mm). The most important changes which represent long-term oscillations were noted during 1782-1794, 1851-1857 and 1912-1918 periods, where trend of radial growth decreased. During the 1778-1781 period radial growth had an increasing trend which culminated in 1782.

The mean chronology of *Cedrus atlantica* at Site II as presented in Figure 5 is constructed by using 38 relative series taken from 20 dominant sample trees. Due to extremely narrow rings in cedar samples, cross-dating was difficult, hence two cores were rejected. The chronology length is 644 years (time span 1368-2011) with a mean tree ring width of 0.730 mm (standard deviation ± 0.131). The cedar chronology had an increasing trend till the year 1398 and this is related to the period of juvenile growth at the beginning of the life cycle. Then juvenile step of radial growth was followed by long-term oscillations period that lasted till 1435. The longest period with a descending trend extended from 1435 to 2011.

Basing on COFECHA and ARSTAN programs we have estimated the basic statistical parameters for each site tree ring width chronology given in Table 2.

When focusing on raw chronologies, the mean ring width at Site I was about two times larger than at Site II. Average correlation among trees for the common overlap period among series is expressed by R_{bar} . It is used to examine the common signal strength of the chronology (COOK et al., 2000); highest strength (0.355) was seen in the cedar forest of Bikrit. The width chronologies of both sites were synchronized with each other. A number of statistical procedures were

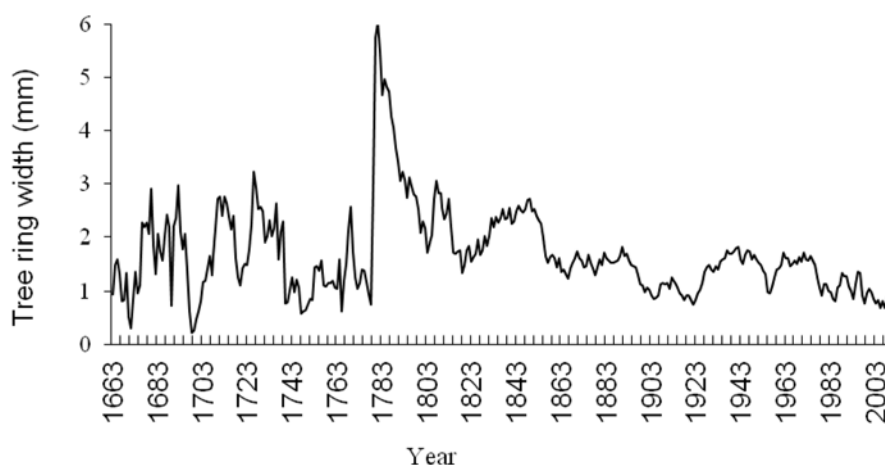


Figure 4. Raw tree ring width chronology of *Cedrus atlantica* in Ain Khahla forest.

Figura 4. Cronologia da largura dos anéis de crescimento crus da *Cedrus atlantica* na floresta de Ain Khahla.

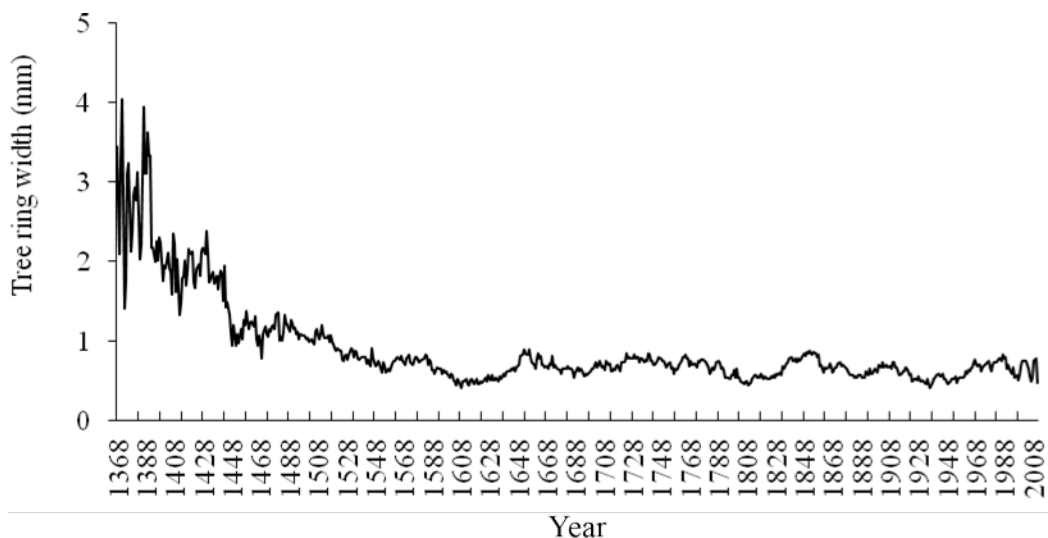


Figure 5. Raw tree ring width chronology of *Cedrus atlantica* in Bikrit forest.

Figura 5. Cronologia da largura dos anéis de crescimento de Raw da *Cedrus atlantica* na floresta de Bikrit.

used to test the strength of series match positions. The five best matches' analysis between the two sites from TSAP cross-dating shows that the significant one begins in 1365 and ends in 1713. The Glk is found to be 67% which is high at statistical significance $P < 0.01$; the TVPB is 3.9 and the CDI gives a fairly a good indication for the correct match, its value is 18 times superior to 10. These results mean that we have a significant crossdating between the 2 sites.

Cedar trees show different growth in different periods of life at both sites. Tree ring width showed higher amplitude in Ain Khahla compared to Bikrit. These sites aren't far from each other and the mean width measurement of the first one is higher than that of the second one. The tree widths of Ain Khahla have extremely low values in years 1672, 1698 and 1699. However, this variable in Bikrit had extremely low values in several years: 1687, 1694, 1695 and

1997. The highest values were found in years 1680, 1692 and 1713 for Ain Khahla and years 1663, 1664, 1672 and 1710 for Bikrit. Indeed, these differences in growth are largely related to the amount of rainfall and local soil of either basaltic or limestone origin. The lower ages obtained at Site I are related to significantly higher growth rates recorded in more moist conditions on basalt. The working hypothesis is that most of this common variance is related to precipitation variation; and through this, a fingerprint of the North Atlantic Oscillation may be found.

Residual site chronologies were created from univariate autoregressive modeling for the years 1663-2011 for Site I, and 1368-2011 for Site II, and master chronology by combining both sites using ARSTAN program as shown in Figure 6.

In general, higher serial correlation of 0.776 was recorded in ARSTAN chronologies, and 0.807 at Site I and Site II, respectively.

Table 2. Statistical parameters of standard chronologies for cedar in both sites.

Tabela 2. Os parâmetros estatísticos das cronologias padrão de cedro em ambos os sítios.

Characteristics	Site I	Site II
Master series	1663-2011 (349 years)	1368-2011 (644 years)
Mean width measurement (mm)	1.570	0.730
Mean interseries correlation (Rbar)	0.268	0.355
Average mean sensitivity	0.296	0.295
Autocorrelation	0.827	0.785
Standard deviation	0.283	0.131
Mean length of series	207.2	501.5
Mean correlation within trees	0.345	0.325
1st-order auto-correlation coefficient	0.720	0.701
Variance due to autoregression (%)	64.9	61.9
Signal to noise ratio (SNR)	5.099	3.494
Agreement with population chronology	0.836	0.331
Expressed population signal (EPS)	0.951	0.948

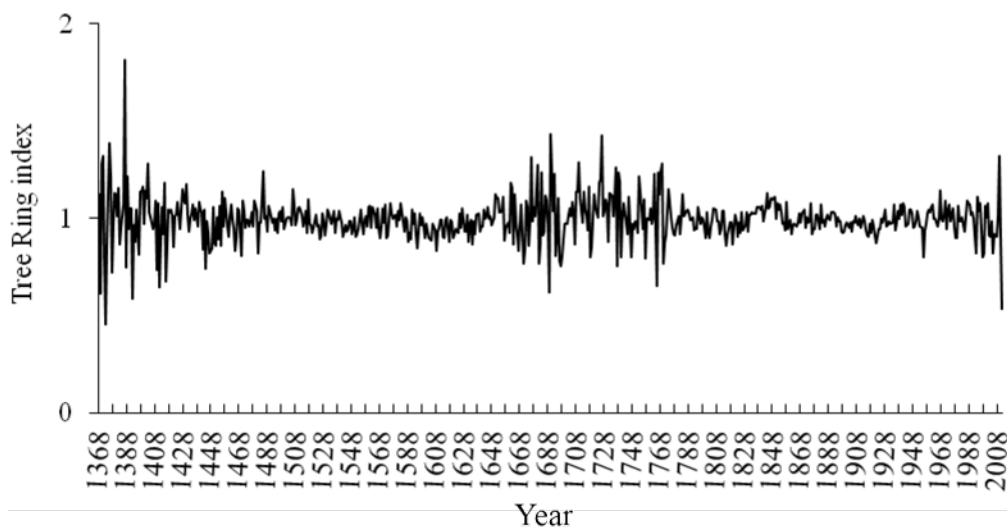


Figure 6. Residual Master chronology of *Cedrus atlantica* in Ain Khahla and Bikrit.
Figura 6. Cronologia mestre residual de *Cedrus atlantica* em Ain Khahla e Bikrit.

Climatic Data analysis

We used meteorological station of Ifrane city for climate records of temperature, precipitation, humidity, snow and wind speed. In this study we used monthly mean temperature and monthly precipitation for half a century from 1958 to 2008 as can be seen in Figure 7. This station is located at 33°32' N, 5°07' W at around 1630 m and about 15 km from Site I and 30 km from Site II as the crow flies. There is no weather station inside the studied area; therefore the location of the Ifrane meteorological station is well-positioned in relation to the sampled sites.

Maximum monthly precipitation was found in December (3406 mm) and a minimum monthly precipitation was recorded in July (242 mm) during the common period 1958-2008. Precipitation from January to April accounted for a major part (45%) of annual precipitation. The average annual rainfall was 1085 mm for the pe-

riod lasting from 1958 to 1980. Over the period 1970-2008, the average was 921 mm/year against 888 mm/year for the period 1981 to 2008. Between the average of 1958-1980 period and that of 1981-2008 period, there was a decrease of 197 mm/year, which represented 18% of the average annual rainfall over the past three decades. If we exclude the rainfall for the years 1996 and 1997 which were high, the average annual rainfall dropped to 839 mm/year; a decrease of 23% annually compared to the average of 1085 mm.

Series of average monthly temperatures at Ifrane station shows an increase for the majority of months and especially for June, March, May and November. The years 1983, 1987, 1990, 1998, 2000 and 2003 had the highest minimum. The year 1995 was relatively warm while years 1981, 1985, 1989, 1992 and 1993 show the lowest average monthly minimum temperatures.

Cedar growth during years 1989, 1990, 1996,

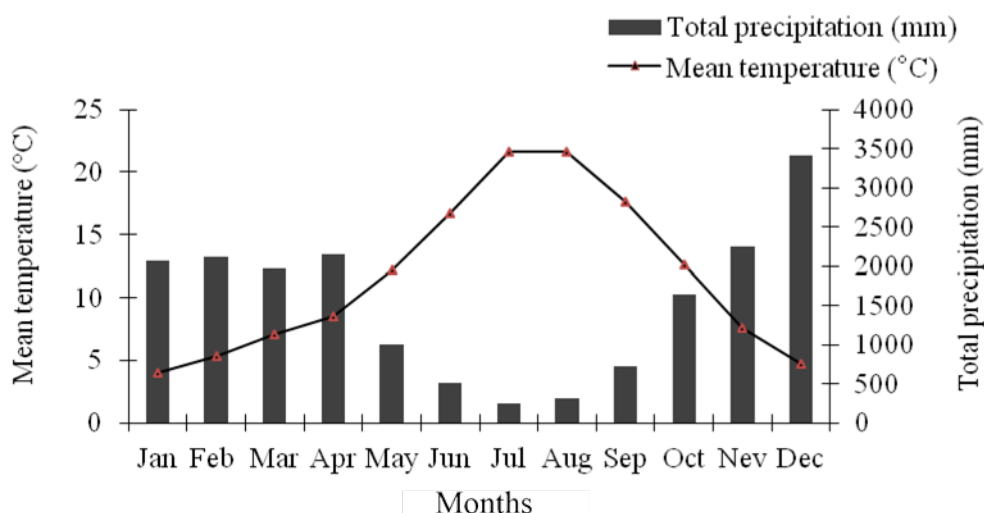


Figure 7. Climatic description of the study area based on climatic data from Ifrane meteorological station (1958-2008).
Figura 7. Descrição climática da área de estudo baseada em dados climáticos da estação meteorológica de Ifrane (1958-2008).

1997 and 2006 occurred in five months but less than 3 months for years 1981, 1982, 1983, 1985, 1986, 1988, 1995, 1999, 2002, 2004 and 2005. The number of dry months/year ranged from 2 months in 1989 and 1996, to 7 months in 1999 and 2002. The year 1995 presented 11 of 12 months when water balance was negative. In this region, Atlas cedar mortality appears to take place mainly in old trees on dry sites such as steep slopes with southern exposure and rocky soils. Generally, Ifrane station has a mild Mediterranean climate, shifting from cool in winter to warm in the summer months of July-September.

Growth analysis

According to analysis of figures 4 and 5 there is a decrease of tree ring width in both sites in the late mid-18th, late 19th, mid-20 centuries and in the most recent decade. Those periods coincided with the most severe multi-year droughts in Morocco, a finding which is in agreement with earlier analyses done by Touchan et al., (2010). Residual chronologies show higher values of mean sensitivity (0.332 to 0.316) showing that high inter-annual variability was present in the ring widths. According to Speer (2010), a value around 0.2 is generally accepted as series that are sensitive enough for climate reconstruction. In addition, higher values of mean sensitivities in residual chronologies, indicate high-frequency radial growth variation through the removal of lagged growth (CULLEN, 2001). First-order autocorrelation is a measure of the influence of the previous year growth on the current year (FRITTS, 1976); values higher than 0.5 indicate

greater influence. The autocorrelation value for standardized series of this study ranged from 0.701 to 0.720.

Chronology confidence and strength of the common signal in the chronology is also estimated by EPS. Though a value of 0.85 is considered reasonable by Briffa (unpub., 1984), no minimum value was determined to ensure that a chronology is suitable for climatic reconstruction. The value of 0.85 has frequently been used as an appropriate cut-off point and benchmark of signal strength of a chronology (COOK; KAIRIUKSTIS, 1990). EPS values were 0.951 to 0.948 for Site I and Site II, respectively, indicating that each chronology was dominated by coherent stand-level signal (SPEER, 2010), hence suitable for past climate reconstruction. Comparing statistical quality of different chronologies is a difficult task if based on Signal to Noise Ratio (SNR). It is mathematically related to EPS with no upper limit.

Climate-growth relationship

We found that tree rings at Ain Khahla is positively impacted by the March total precipitation and negatively correlated with the monthly mean temperature of June, which causes substantial growth reduction. Consequently, the precipitation in the spring months is significant for early-wood formation. This is important for annual radial growth because the vegetation period starts in the middle of April. However, at site II, a highly significant positive correlation between tree ring chronologies with September temperature is recognized. Temperature dur-

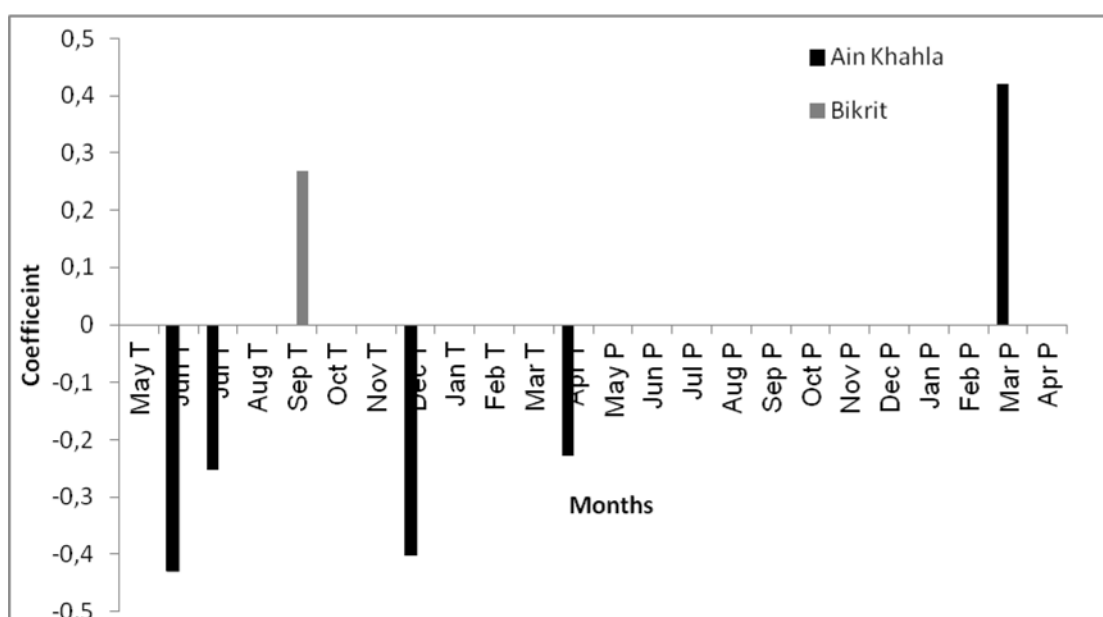


Figure 8. Significant correlations between annual radial growth and monthly climatic variables in both sites.
Figura 8. Correlações significativas entre o crescimento radial anual e mensal variáveis climáticas em ambos os sítios.

ing the end of the second part of the growing season (September) is important for latewood production (growing season ends in October). Low temperatures during winter (December), and especially frosts, cause substantial growth reduction and delay the growth starting during spring season. Those results indicated that ring width was primarily controlled by both temperature and precipitation. Also, the cedar radial growth continues to be dependent on summer temperature. For cedar grown under Mediterranean climate, high temperatures and low precipitation during growing season may cause water stress, which is the main limiting factor for tree growth. The values of tree ring series and the results of response analysis showed that cedar chronologies in Ain Khahla and Bikrit can be used for climatic reconstruction. However, for better cross-dating and climate reconstruction over a 500 year period, sample sizes should be increased for cedars in many forest sites. One of the major difficulties in dendroclimatic reconstruction of past climate in Morocco is the paucity of long term meteorological records for statistically calibrating tree rings.

CONCLUSION

The main purpose of this study was to explore the potential of tree ring records from high elevation cedar forests of Morocco for identifying major patterns of climatic variability. It demonstrates that it is possible to crossdate *Cedrus atlantica* and to develop dendrochronological series from these data; the ring boundaries were often clearly visible and therefore common patterns of thin and wide rings were often distinguishable. Although both sites, Ain Khahla and Bikrit, have relatively similar climatic conditions they showed differences in tree-ring width chronology.

The derived chronology is well correlated with temperature and precipitation, which indicates that cedar has a potential to be used for dendroclimatic analysis. This approach will be more significant if meteorological station climate data correlated quite close with the ring width series and the calibration period was quite long. The results of the analysis of climate and tree growth relationships indicated that the monthly mean temperature of June had a significant effect on the tree-ring growth. In addition, there was a positive relationship between March and September precipitations and tree ring width at sites Ain Khahla and Bikrit, respectively, which

suggests that spring and summer snow melt is important for cedar growth. It may be possible to obtain longer chronologies by sampling new cedar sites which offer the potential for developing a more extensive network of cedar sites from Middle Atlas and extending our knowledge of the spatial pattern of Moroccan climate.

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