Impact of drought and site characteristics on vitality and radial growth of Cedrus atlantica Manetti in the Ouarsenis massif (Algeria)

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IMPACT OF DROUGHT AND SITE CHARACTERISTICS ON VITALITY AND RADIAL GROWTH OF *CEDRUS ATLANTICA* MANETTI IN THE OUARSENIS MASSIF (ALGERIA)

Mohamed SARMOUM[1*], Rafael NAVARRO-CERRILLO[2], Frédéric GUIBAL[3], Fatiha ABDOUN[4]

[1]Laboratory of Plant Physiology and Out Soil Culture, Faculty of Natural and Life Sciences, Ibn Khaldoun Tiaret University, Algeria
[2]Department of Forest Engineering, Group of Evaluation and Restoration of Agricultural and Forestry Systems, DendrodatLab - University of Córdoba, Spain
[3]Mediterranean Institute of Biodiversity and Marine and Continental Ecology (IMBE), UMR 7263 CNRS-IRD, Aix-Marseille University (AMU), Aix-en-Provence, France
[4]Laboratory of Plant Ecology and Environment, Faculty of Biological Sciences, University of Science and Technology Houari Boumediene (USTHB), Algiers, Algeria
*Corresponding author: sarmoum.med82@gmail.com

ABSTRACT

This work investigates the impact of drought and site characteristics on vitality and radial growth of Atlas cedar (*Cedrus atlantica* Manetti) in Ouarsenis cedar forests (Algeria). The choice of this zone was dictated by the appearance of the phenomenon of decline since the 1980s and the lack of study on this subject. Our hypothesis seeks to understand how climatic factors interacted with site characteristics affected radial growth and vitality of Atlas cedar. We used the dendroecological approach where 09 populations of Atlas cedar distributed on the two cedars of Ouarsenis (Theniet El Had and Ain Antar) and covering a varied range of environmental conditions (substrate, altitude, exposure) were studied. The climatic signal recorded in ring-width series of Atlas cedar trees was investigated by bootstrapped response function over the period 1936-2010. The results show a good agreement between the individual curves and those of mean site chronologies, which reflects the influence of climatic factors on tree radial growth. Atlas cedar is very sensitive to rainfall fluctuations throughout the year. This sensitivity is more pronounced for populations located at low altitude, on steep slopes and on sand stone or marl substrates. The dry years induced a significant radial growth decline and triggered massive tree mortality, particularly in 1983, 1984, 1988, 1994 and 2002. The vitality of the species seems to be conditioned by the frequency of drought years.

Keywords: *Atlas cedar, decline, Algeria, radial growth, drought.*

INTRODUCTION

There is now a broad consensus that climate change has already affected or is affecting the functioning and production of plant cover, including forest stands (Spathelf *et al*., 2014). However, the response of forest species is complex and the impact of changing climate conditions on mortality rates observed during the last decade in several species remains poorly understood (Allen *et al*., 2010). In North Africa, climate has been dominated by drought over recent decades (Touchan *et al.,* 2008). Reduced rainfall during the wet period (October-May) and increased temperatures during the same period would result in an increase in the dryness and summer drought (Dai, 2011). This situation may jeopardize the existence of several species including those that are sensitive to drought (Linares *et al.,* 2011). The Atlas cedar is an endemic species in the highest mountains of Algeria and Morocco where it occupies a very fragmented area (Benabid, 1994). This species fits better in humid and sub-humid bioclimate and is averse to the long and repeated droughts (Ladjal *et al*., 2007). Currently, this species is experiencing severe deterioration marked by a lack of natural regeneration and massive tree mortality, and the absence of silvicultural practices has worsened the situation (Messaoudene *et al.,* 2013). The phenomenon of Atlas cedar decline was first observed in the 1980s, but has become alarming in recent years (Bentouati et Bariteau, 2006). Although the causes of this problem remain uncertain, the hypothesis of impacts of climate change cannot be excluded (Linares *et al*., 2011; Kherchouche *et al*., 2013). Drought impact on vitality and radial growth of Atlas cedar has been recently studied (Linares *et al.,* 2013; Slimani *et al.,* 2014). However, these studies have focused on one site, without taking into account the environmental variability. Our project assessed the impact of drought, in addition to other the environmental variables, on the vitality and the radial growth of Atlas cedar through a retrospective approach using tree rings as a recorder of climate signals. We seek to determine whether the impact of drought can be influenced by some site conditions such as altitude, slope and substrate. We also attempt to highlight a possible correlation between drought and the observed cedar decline during several decades.

MATERIAL AND METHODS

Description of the study area

The study was conducted in the Ouarsenis Massif (North West of Algeria) (Figure 1), which houses two cedar forests: “Theniet El Had” (1000 ha) and “Ain Antar” (500 ha). These are natural stands of Atlas cedar developing in substantially variable environmental conditions. The current climate trend is characterized by a decrease in the annual precipitation by ca. 25% and the increase in temperature throughout of the year (Figure 1). This would have increased the length of the dry period and resulted in a shift of bioclimate from sub-humid to semi-arid.

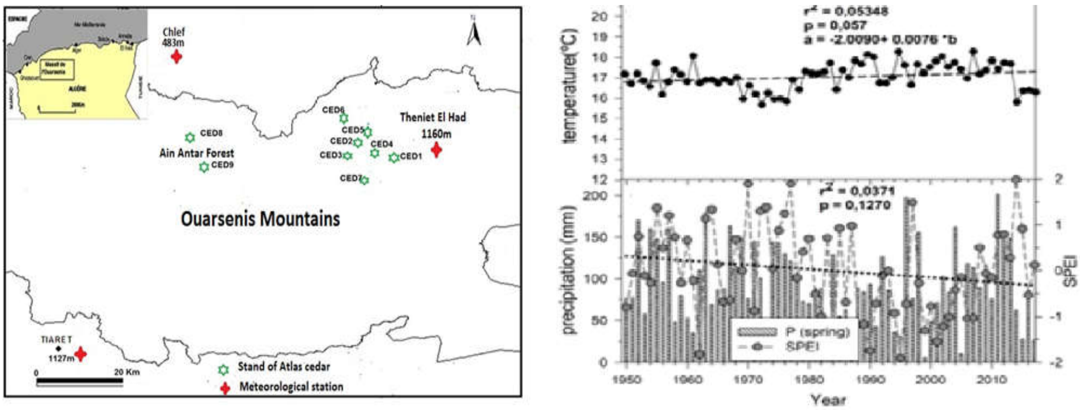

Figure 1. Location of the study area, sites sampled, annual climate trends of mean temperature and total precipitation in the study area and for the period 1950-2010.

Study Material

Nine sites were sampled and analyzed, seven from “Theniet El Had” forest cedar (CED1 to CED7) and two from “Ain Antar” (CED8 and CED9). Site selection was based on the following variables: altitude, slope, exposure and soil type (Table I). At each site, 15 trees from dominant and co-dominant trees were selected and sampled. Two cores were extracted from each tree at a height of 1.30m. The collected samples were processed and analyzed according to standard procedures in dendroecology (Fritts et Swetnam, 1989).

Data processing and analysis

Following fine-sanding, the cores were crossdated by visual comparison under a dissecting microscope using standard dendrochronological techniques (Fritts, 1976).Ring widths were measured using a LINTAB6 measuring table with a resolution of 0.001 mm and the TSAP software (Rinntech ®)to obtain elementary core ring-width series.

Chronology descriptive statistics

For each series, the statistical parameters traditionally implemented in dendrochronology were calculated (Fritts, 1976; Cook et Kairiukstis, 1990):

Expressed population signal (EPS): an EPS value at least 0.85 constitutes an indicator of agreement of the simple chronology variance with that of theoretical population chronology.

Mean sensitivity (MS): calculated for each individual tree and site chronology, considering the absolute relative difference in width from one ring to the next. According to Fritts (1976), threshold of 0.20 defines sensitive (MS >0.20) and complacent (MS<0.20) population.

First-order autocorrelation coefficient (AC): used to estimate the degree of persistence in time series, by calculating the correlation between the time series lagged in time with a lag equal to one year (Fritts, 1976).

Table 1. Site description, geographic coordinates, elevation, aspect, slope, soil and samples. The cedar forest of “Theniet El Had” contains 07 sites (CED1 to CED7) and that of “AinAntar” two sites (CED8 and CED9).

Sites	Coordinates	Elevation (m)	Exposure	Slope %	Soil type	Trees (cores)
CED1	35°53’23’’N2°00’02’’E	1460	NNE	20-30	Vertisoil	15 (29)
CED2	35°51’44’’N1°59’18’’E	1520	NE	50-60	Colluvial soil	15 (27)
CED3	35°51’08’’N1°57’08’’E	1700	N	50-60	Colluvial soil	15 (28)
CED4	35°52’06’’N1°58’01’’E	1325	NE	10-20	Colluvial soil	15 (30)
CED5	35°52’24’’N1°58’25’’E	1420	NNW	30-40	Colluvial soil	15 (25)
CED6	35°52’35’’N1°56’00’’E	1420	NW	20-30	Colluvial soil	15 (30)
CED7	35°51’50’’N1°57’27’’E	1550	SW	50-60	Colluvial soil	15 (23)
CED8	35°53’34’’N1°39’25’’E	1150	NW	20-30	Lithosoil	15 (29)
CED9	35°53’30’’N1°38’48’’E	1450	NNW	50-60	Lithosoil	15 (27)

Rings-width standardization

The intent of standardization is to remove non-climatic age trends from ring-width series (Cook *et al.,* 1990). In this paper, we applied two standardization methods; the first one uses a detrending filter with a 20-year window (low-pass filter) to generate indexed series for each population. The second involves Autoregressive modeling (ARMA) and the bootstrapped method to calculate response functions (Guiot, 1986). Standardizations methods were applied using the package PPPbase (Guiot et Goeury, 1996).

Climate-growth relationship

To understand the relationship between tree growth and climate, response functions were developed (Fritts, 1976; Cook et Kairiukstis, 1990). An autoregressive model (ARMA) was selected to prewhiten the series before computing bootstrapped response functions using the package PPPBase (GuiotetGoeury, 1996).

Climate regressors included monthly precipitation (P),maximal (TM) and minimal temperatures (Tm) over a period of 12 months from October of year *t-1*toSeptember of year *t*. Climate data used are those of meteorological stations of Tiaret (1936-2010).

Results with the highest correlation coefficients and statistical significance merit further interpretation. Statistical significance depends on the "R / S" ratio which expresses the ratio between the correlation coefficient of the period of verification and its standard deviation. Based on the "R / S" value, four significance levels are defined (Table II). Only response functions whose "R / S" is greater than or equal to 1.96 are significant (p>0.05) and will be discussed in terms of tree-ring to climate relationships.

Table 2. Overall significance of the response functions. (R/S is the ratio between the correlation coefficient of the period of verification and its standard deviation). Are considered significant, the response functions where R / S> 1.98 (95%).

R/S	Code	signification
1.65-1.96	1	90%
1.96-2.58	2	95%
2.58-3.29	3	99%
>3.29	4	99.9%

RESULTS AND DISCUSSION

Ring-width chronologies

The samples were successfully crossdated. During this step, we found difficulties related to the presence of very narrow, incomplete or missing rings, especially near the bark (Figure3). False rings are very rare in chronologies of Atlas cedar. Raw ring-width series show a clear decreasing trend with age and diameter increase. The mean site chronologies exhibit similar growth patterns emphasizing growth increase sequences (1883-1891, 1909-1912, 1928-1932, 1972-1976) and growth decrease sequences (1867-1872, 1876-1881, 1920-1925, 1942-1947, 1958-1961, 1983-1994, 1999-2002). These variations are common to Atlas cedar populations and caused by a common factor (e.g.climate).

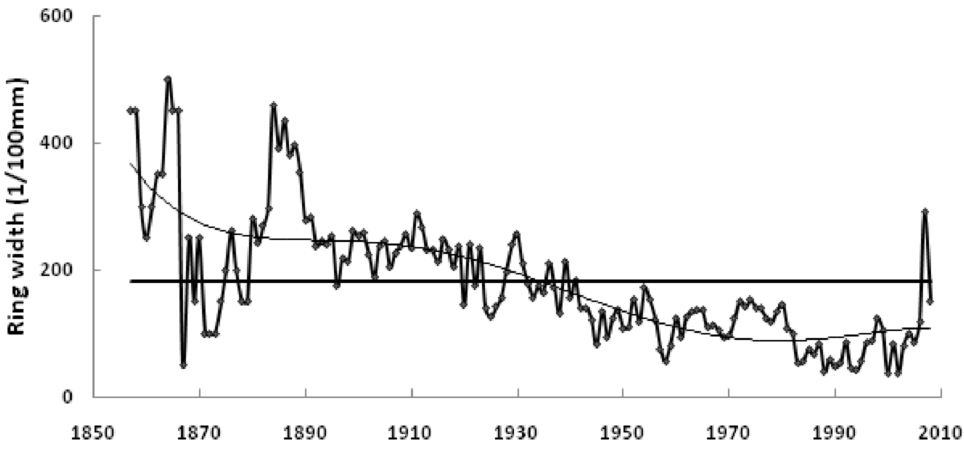

Figure 2.Example of ring-width chronologies of Atlas cedar in Ouarsenis Mountains.

Chronology descriptive statistics

Expressed population signal (EPS) values exceed the threshold of 0.85, suggesting the samples are capturing a common signal at the site. These results support strong correlation and coherence between the chronologies (Table III).

The mean sensitivity (MS) ranges from 0.18 to 0.43 for the individual series and from 0.17 to 0.30 for site chronologies (TableIII). Higher values of mean sensitivity (MS>0.20) are recorded especially at low elevation and/or sandstone and marl substrates (CED1, CED2, CED3, CED4) and high slope (CED9).

First-order autocorrelation coefficients (AC) range from 0.13 to 0.20, indicating a low dependence of current growth on previous year's growth. The longest tree-ring series is 221 years (CED8) and it covers the period 1789-2010.

Radial growth of Atlas cedar in the Ouarsenis Massif seems to be modulated by several environmental factors, including climate, elevation, slope and soil. These factors operate mainly on the water balance in the soil and hence the length of the growing season (Khatouri et Denis; 1990). Considering the agreement between the growth curves of several stands, we can suggest that the factors that govern Atlas cedar radial growth are common and mainly related to climatic factors. These studies support results obtained for this species in Morocco (Till, 1986) and southeastern France (Guibal, 1985).

Table 3. Statistical parameters calculated for each site (chronology; Expressed population signal: EPS; mean sensitivity: MS; first order autocorrelation coefficient).

Sites	Chronology (age)	EPS	Cores MS (Mean)	Site MS	AC
CED1	1857-2010 (153)	0.94	0.25-0.40 (0.32)	0.25	0.162
CED2	1850-2010 (160)	0.87	0.18-0,36 (0.25)	0.19	0.158
CED3	1877-2010 (133)	0.89	0.19-0,27 (0.22)	0.17	0.173
CED4	1930-2010 (81)	0.93	0.29-0.43 (0.33)	0.30	0.203
CED5	1870-2010 (140)	0.89	0.25-0.38 (0.29)	0.27	0.171
CED6	1860-2010 (150)	0.95	0.25-0.41 (0.32)	0.29	0.162
CED7	1891-2010 (119)	0.89	0.19-0.28 (0.23)	0.19	0.186
CED8	1789-2010 (221)	0.92	0.21-0.29 (0.24)	0.20	0.167
CED9	1866-2010 (144)	0.87	0.22-0.29 (0.25)	0.21	0.134

Climate-growth relationship

In all populations precipitation from October$_{t-1}$ to April$_t$ positivelycorrelates ring-width. Growth is also positively relatedto August and September precipitation. In contrast, negative relationships are found between May to June precipitation and ring width. Lowland populations (CED1, CED4, CED5 and CED6) are more sensitive to precipitation throughout the year. Minimal temperatures are positively related to radial growth in December and January (CED1, CED3, CED7, and CED9), February (CED2, CED4, CED5, CED6 and CED7) and March (CED5 and CED6) but negatively in November (CED5 and CED7). As for maximum temperatures, they are negatively related to ring width, especially in summer (Figure3).

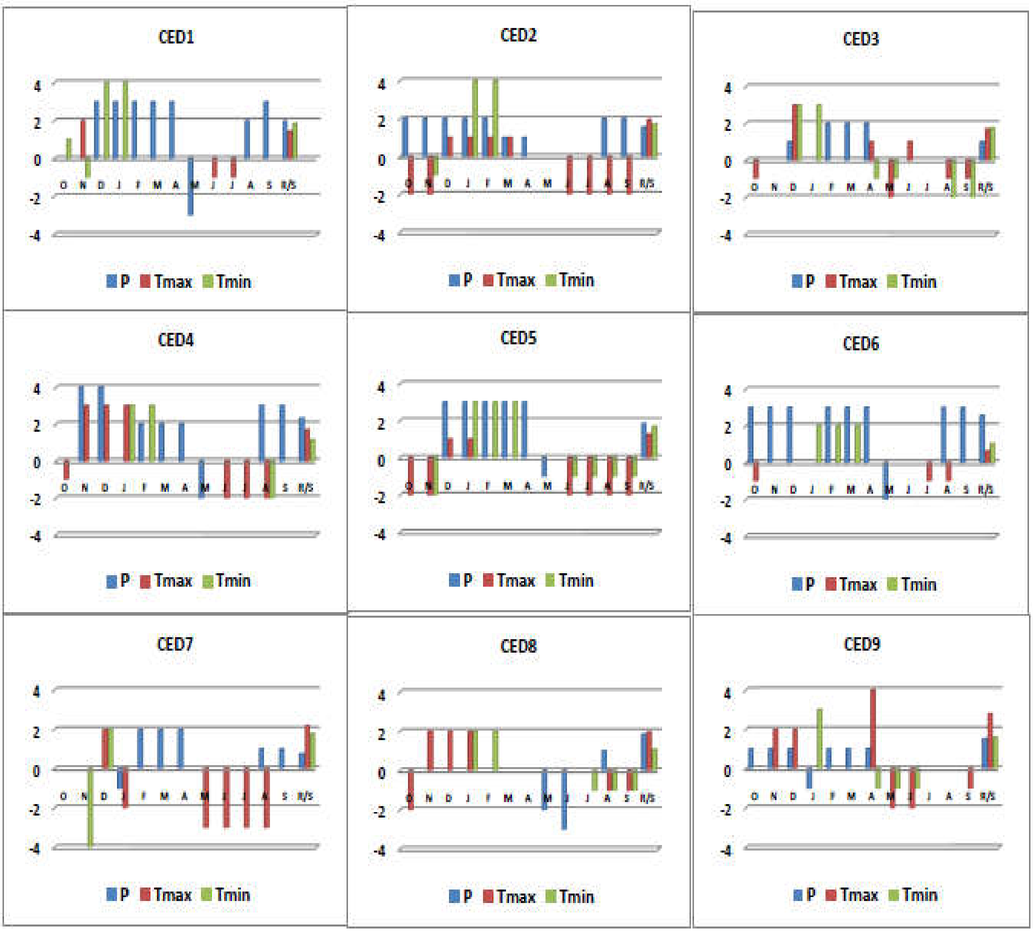

Figure 3. Response functions of Atlas cedar at the 9 sites (1936-2010). Bootstrap values (v) are significant at v> 2. The black bar indicates the relationship with monthly precipitation (P), stoneware with maximum temperatures (Tmax) and the white with the minimum temperatures (Tmin)

Atlas cedar shows a positive relation with precipitation, especially those that precede and coincide with the ring formation. This relationship shows that cedar radial growth is mainly limited by water supply during both the months prior to cambial activity (November to February) and the period of cambial activity (March-April).The positive relation with winter precipitation could be attributed to water storage in the soil for use during the growing period (Till, 1986).An ongoing cambial activity from August to September could be a possible cause of the positive relationship shown between precipitation and ring width (Ladjal *et al*., 2007).Temperature, perhaps play a decisive role in Atlas cedar radial growth. Its role is positive in winter but negative in summer. The positive role of winter temperatures can be explained by its influence on photosynthesis during mild sunny winter days. In contrast, the negative effect of high temperatures during the summer underlines the importance of water balance deficit as a result of low precipitation and high temperature (Till, 1986). Touchan *et al*. (2017) showed that Atlas cedar has positive relationships with winter and spring precipitation and a negative response with spring and summer temperatures. In addition, compared to other species in the study area (Sarmoum *et al*., 2016; Hibbani et Abdoun, 2018), Atlas cedar growth is closely related to precipitations and appears more sensitive to drought. We found also that populations located at low altitude and/or marl and sandstone substrate are more sensitive to precipitation. This sensitivity is demonstrated by high mean sensitivity coefficients (MS) and a positive relation with precipitation throughout the year.

Impact of drought on radial growth and stands health

The dry years cause a sudden and prolonged decrease in soil water reserves and expose trees at a high risk of water stress, which finds its peak in summer (Ladjal *et al*., 2007). Several studies have shown that site characteristics help to increase the effect of drought (Kane *et al.,* 2014). We suggest that responses of growth to drought were conditioned by the local site characteristics related to the variability in soil water-holding capacity.The effects of water stress on trees are multiple: combination of a high water deficit and high evapotranspiration may cause a malfunction of the water supply and lead to xylem embolism and cavitation (Meinzer et McCulloh 2013).In species well adapted to high levels of water stress such as Aleppo pine, evapotranspiration is controlled by the opening and closing of stomata when water stress occurs (Borghetti *et al.*, 1998); in this case, the risk of cavitation and embolism of xylem is limited (Martinez-Vilalta et Pinol 2002). However, Atlas cedar continues its physiological activities under high levels of water stress, which increase the risk of xylem embolism (Ladjal *et al.*,2007; Gaba-Chahboub *et al.*, 2016).The vulnerability of xylem may also change with the age of the tree; older trees are more vulnerable to xylem embolism which could contribute to a gradual loss of functionality of the xylem and thus the mortality of the tree (Linares *et al.*, 2013).Loss of the tree vitality due to water stress decreases tree resistance to pathogens and parasite attacks (Raouault *et al.*, 2006). It therefore seems logical that after long periods of drought, high mortality in forest stands is observed (Cailleret *et al.*, 2014). In the future, the importance of drought as a limiting growth factor is expected to increase in North Africa (Barkhordarian *et al.*, 2013) and extreme events such as droughts will be more frequent (Vizy et Cook 2012). The vitality of Atlas cedar seems to be conditioned by the frequency of drought years.

CONCLUSION

This work was able to highlight the relationship between drought and site characteristics to explain the decline in growth and the loss of vitality in Atlas cedar in the Ouarsenis massif. As a result, the years of drought adversely affected cedar growth, particularly on marl and sandstone substrate and/or low altitude, where massive tree mortalities were recorded over the years 1983, 1984, 1988, 1994 and 2002. It is necessary to establish a surveillance network in all cedar forest affected by decline.

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