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Tree ring growth of Atlas Cedar, facing climate changes in inter-annual and seasonal scales in Western Rif (Morocco)

La croissance des cernes du Cèdre de l'Atlas face aux changements climatiques à l'échelle inter-annuelle et saisonnière dans le Rif Occidental (Maroc)

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Abstract. A dendroecological study was undertaken to analyze the radial growth evolution of a natural stand of Atlas Cedar, *Cedrus atlantica* (Endl.) Carrière, in relation with climatic conditions. The study took place in the forest site named Bab Larz (BAL) located at 30 km from Chefchaouen city (Western Rif). The low intensity forestry practiced in the stand largely explains the high quality of trees. A number of 40 cores was sampled on 20 trees (2 cores / tree). The ring analysis results show that the age of Cedar trees is 144 years (1865-2008). After a decay period of 26 years (1886-1911), the mean ring width is 1.69 mm per year since 1912.The studied site is sensitive to climatic factors (the mean sensitivity = 0.25). The impact of climate was analyzed by comparing changes in the full ring to climatic data provided by Chefchaouen weather station during the period 1977-2008. Thus, a highly significant negative correlation (P <0.01) between the annual ring development and the mean monthly temperature during the summer months (June and July) was highlighted. However, ring width has a positive and highly significant correlation with precipitation of September (P <0.01) and a significant positive correlation (5% level) with those of December of the previous season growth and April of the current growing season. The linear climate modeling explains 53.4% of the tree-ring width variability and suggests that the development of a ring depends mainly of summer temperatures in particular that of June. Furthermore, ecophysiological interpretations of climate correlations are discussed.

Keywords: Dendroecology, *Cedrus atlantica* (Endl.) Carrière, climate change, Rif, Morocco.

Résumé. Une étude dendroécologique a été entreprise afin d'analyser l'évolution de la croissance radiale d'un peuplement naturel du Cèdre de l'Atlas, *Cedrus atlantica* (Endl.) Carrière, en fonction des conditions climatiques. L'étude a eu lieu dans le site forestier dit Bab Larz (BAL) situé à 30 km de la ville de Chefchaouen (Rif Occidental). La faible intensité de l'activité forestière dans le peuplement explique, en grande partie, la qualité élevée des arbres. Un nombre de 40 carottes a été échantillonné sur 20 arbres (2 échantillons / arbre). Les résultats de l'analyse des cernes montrent que l'âge des arbres est de 144 années (1865-2008). Après une période de décroissance de 26 ans (1886-1911), la largeur moyenne du cerne atteint 1,69 mm par an depuis 1912. Le site étudié est sensible aux facteurs climatiques (la sensibilité moyenne = 0,25). L'impact du climat a été analysé en comparant les changements au niveau du cerne aux données climatiques fournies par la station météorologique de Chefchaouen au cours de la période 1977-2008. Ainsi, une corrélation négative très significative (P <0,01) entre la croissance annuelle des cernes et la température mensuelle moyenne durant les mois d'été (juin et juillet) a été soulignée. Cependant, la largeur du cerne a une corrélation positive, très significative avec les précipitations du mois de septembre (P <0,01) et une corrélation positive significative (niveau de 5%) avec celles de décembre de la saison de croissance précédente et celles d'avril de la saison de croissance actuelle. La modélisation climatique linéaire explique 53,4% de la variabilité des largeurs de cernes et suggère que le développement d'un anneau de croissance dépend principalement des températures estivales en particulier celles de Juin. Par ailleurs, des interprétations écophysiologiques des corrélations climatiques ont été discutées.

Mots-clés: Dendroécologie*, Cedrus atlantica* (Endl.) Carrière, changement climatique, Rif, Maroc.

INTRODUCTION

In the current context of climate change, the knowledge of the climate-tree growth relationships is important to understand forest ecosystems evolution and to develop models related to growth and climate (IPCC 2007). According to recent climate expectations, the drought frequency and intensity are likely to increase in the South and Central Europe and in the Southern Mediterranean region. These changes may reduce forest productivity as was, eventually, the case in 2003 and they could affect forest species distribution (Milly *et al*. 2005). The climate variation that affects tree growth can be materialized via tree rings. In recent years, the frequency of abnormal changes of weather conditions has stressed the importance of ecological tree rings research (Filipe *et al*. 2010). In fact, each year, the tree rings register their functioning in relation to climate changes. The relationships between Cedar radial growth and climate were frequently studied in several Mediterranean countries such as Jordan, Turkey and Tunisia (Touchan *et al*. 1999, 2007, 2008b). However, Till (1987) notes that this type of research in the Moroccan forests is limited to few sites.

In Morocco, particularly in the Atlas Cedar forest, the oldest and most dominant Cedar specimens have heights between 40-60 m and nearly 1200 years of age (Cheddadi *et al*. 2009). These trees are considered as a real living memory of climate change.

Other studies showed that the Atlas Cedar develops individualized forest stands, mainly in sub-humid, humid, perhumid, cold and very cold climate and it grows in a rainfall range between 500 and 1700 mm per year (Benabid 2000). In the Rif area that benefits from the combined influence of the Mediterranean sea and Atlantic ocean, where the rainfall may reach 2000 mm in high altitudes, the Cedar forest occupies an area of 15 000 ha (Benabid 2000). This species exists sporadically in the upper levels of the geologic Numidian chain. In the geologic dorsal limestone, Cedar is in competition with another species: the Fir tree of Morocco (*Abies marocana* Trabut) at an altitude between 1500 and 1900 m. Also, *Cedrus atlantica* developed better forest stands mainly on non-calcareous substrate in the central part of Rif Mountains (M'hirit 1994). The objectives of this study are:

- Highlight the effect of climate change on Cedar tree growth in the Western Rif, Morocco
- Understand the interaction between the structure and composition of Mediterranean forest stands and climate factors.

MATERIAL AND METHODS

Study area

The sampled Cedar forests are located at high altitudes of Rif Mountains. These forest stands are still looking in good conditions and human impacts on forest may be emphasized by climate change or other environmental factors.The study area called "Bab Larz" (BAL) [34°58'N,4°44' W] is characterized by well-looking forest stands (Fig. 1). Its altitude is 1640 m, the substrate is of sandstone type with a rich and deep soil. The dominant tree species is *Cedrus atlantica*.

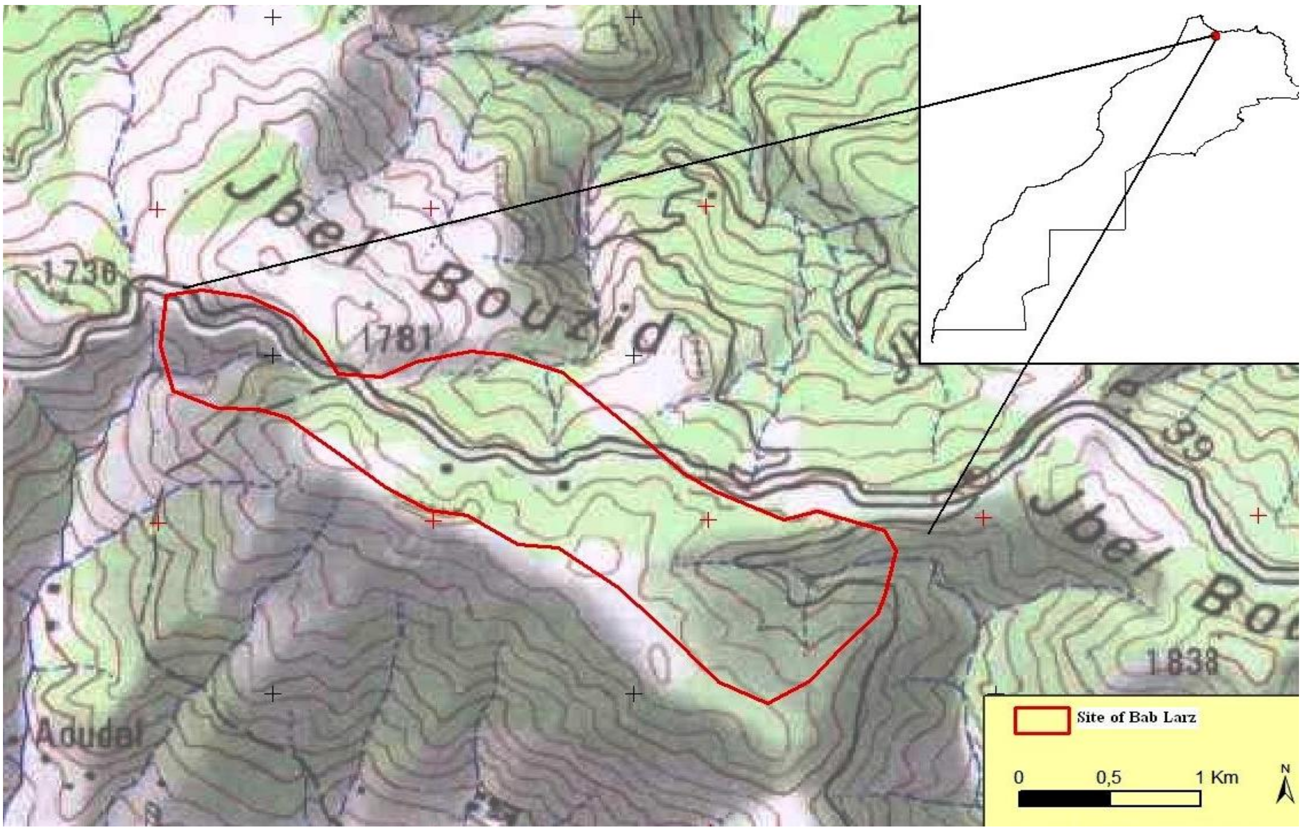

Figure 1. Location of the studied site Bab Larz (topographic map, Ghafsai 1 / 100 000)

Sampling and data collection

The sampling site was located in a southeast aspect with an average Cedar tree circumference of 2 m, an average height of 28.3 m and a mean distance between trees of about 10.5 m. A number of 20 trees was selected avoiding visible wood defects and 2 cores per tree were sampled (i.e. a total of 40 cores). An increment borer was used to take core samples oriented across the slope and at a height of 1.3 m above the ground. Then, the cores are numbered and stored in special tubes. These cores are glued onto grooved strips and polished using sand paper to ensure a good visibility of tree rings and every detail of wood structure and to facilitate their measurement which was performed with a precision of 1/100 using a video-specific computerized system called (LINTAB 5™). Each individual series was crossdated using a Time Series Analysis Program for Windows (TSAPwin) that performs needed statistics and crossdating of series (Rinntech 2005). In order to eliminate the influence of age on growth, the raw series are then transformed into indices by filtering and a master chronology is determined by calculating the mean tree ring width during each year (Rolland 1993). The work was conducted at Wood Technology Laboratory of the National School of Forestry Engineering (ENFI), Sale, Morocco.

Climate data collection

The climatic data (1977-2008) used in the determination of tree ring width-climate relationships (temperature and monthly rainfall) are from the Chefchaouen meteorological station (35°00' N, 5°04'W), which is the closest one to the study area (30 km as the crow flies). The Chefchaouen station (692 m) is situated at a lower altitude compared to Bab Larz. In addition, the pluviometric gradient is 7,2 mm/ 100 m, the thermal gradient of minimum temperatures is -0,61°C/100 m, and the thermal gradient of maximum temperatures is -0,46°C/100 m (Taiqui 2005).

According to this data, the studied area is of a Mediterranean sub-humid climate with mean annual rainfall of 758 mm, primarily recorded from November to March which proportion is 60 % of total annual precipitation (Fig. 2). A number of 5-10 days of snow are recorded each year.

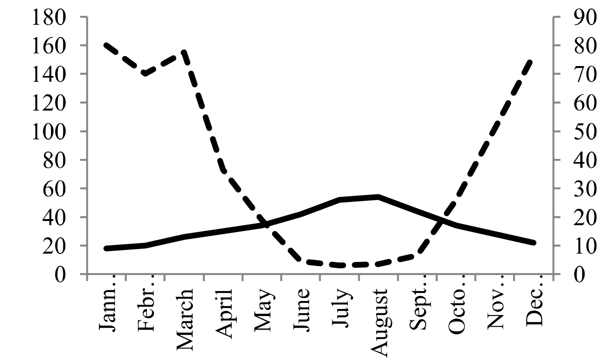

Figure 2. Ombrothermic diagram of Chefchaouen (1977-2008) (____ : P (mm) ; _ _ _ : 2T (°C))

Statistical treatments

The data from ring core samples was treated for age verification using COFECHA software (Holmes 1983). To determine the interannual variation of dendrochronological signal, Arstan software was used to standardize individual series and to eliminate the ring width variation part unrelated to climate ("noise") (Cook & Holmes 1984). To assess the quality and strength of the climate signal contained in tree rings, four statistical parameters were calculated:

- The Mean Sensitivity (MS) to characterize globally tree response to annual climatic fluctuations (Fritts 1976).
- The Inter-Correlation (IC) to verify the goodness of synchronism between series.
- The Auto-Correlation (AC), to highlight the growth importance of the previous year (and thus of climate) comparatively to that of the current one.
- The Expressed Population Signal (EPS) and the Mean Correlation Coefficient between trees (RBAR) were used to verify crossdating and robustness of climate signal carried by the rings (Cook & Kairiuktis 1990). In the Mediterranean area, the growing season for forest vegetation lasts from March to September (M'hirit 1982). An orthogonalized linear regression was used to determine the response function of ring width to climate. The climate data used are the 12 monthly variables of temperature and precipitation from May of the year (t-1) to April of the following year (t).

The SPSS (version 20) software was used to estimate statistical parameters of quality control such as the correlation coefficient (R) to assess the degree of relationship between the annual growth of *Cedrus atlantica* and climate, and the coefficient of determination (R^2), which gives the explained proportion of variance. All these computations are used to identify the key variables and climatic periods playing a significant role in the growth of trees.

RESULTS

Statistical characteristics of ring chronology of *Cedrus atlantica*

Dendrochronological analysis showed that the mean sensitivity of rings of *Cedrus atlantica* was 0.251 (Tab. 1) exceeding the acceptable threshold of 0.10 and the value of the EPS chronology is greater than the acceptable value of 0.85 (Mccaroll & Loader 2004). Since the chronology of trees showed a high value of standard deviation (0.42) and low values of the mean sensitivity and the 1st order autocorrelation coefficient (around 0), it may contain important ecological information (Shao & Wu 1994). In addition, the high values of the Signal to Noise Ratio (SNR) and the Explained Variance (VFE), 23.66 and 58.92 respectively, justify that the Cedar forests of Bab Larz is appropriate for anecological analysis of the rings in Western Rif. All these results indicate that the growth of Cedar trees was more sensitive to climatic changes.

Table 1. Characteristics of Atlas Cedar tree rings-2008.

Parameters	Site of Bab Larz (BAL)
Master chronology length	1865-2008 (144 years)
Total sample / trees number	40/20
Standard deviation	0.420
Mean ring width (mm)	1.73
Mean Sensitivity	0.251
Intercorrelation between series	0.443
Autocorrelation	0.388
Mean correlation coefficient between trees (Rbar)	0.789
Mean years number measured from cores (years)	108.8
1st order autocorrelation coefficient	0.123
Variance due to autoregression (%)	48.8
Signal to Noise Ratio (SNR)	23.66
Expressed Population Signal (EPS)	0.993
Explained variance (Variance in First Eigenvector, VFE) in%	58.92

The analysis of tree ring width was done on measured data. Also, the indices, related to the ratio of ring width to total width of wood for a given period, were used (Fig. 3). The results showed that the majority of obtained total chronologies were covering a time period from 1865 to 2008. The variation average curve of ring width of different trees in the study site (Fig. 3) showed a trend of decreasing width since the early years of growth. Indeed, several characteristic years of a negative trend were identified

(Fig.3). The period (1870-1885) is characterized by favorable climate conditions (strong and regular precipita-tions) compared to the period 1886-1911 (growth reduction of 20% on average) with decreasing trends. Indeed, during this last period, the influence of the relatively arid climatic conditions is observed.

However, a "normal" growth rings recovery after a major stress observed from the early 1958 to 1991 could probably correspond to particularly favorable weather conditions. Also, the master chronology of Cedar clearly showed a decrease in the tree ring width with age and an increase of the main stem circumference over the period 1992.

Relationship between Atlas Cedar ring width and climatic factors

The statistical results showed that there was a highly significant negative correlation ($p<0.01$) between ring width of Cedar and the mean monthly temperature in summer time (June-July) and in autumn (October) (Fig. 4). In May, as the temperature raises, tree grow this accelerating, which is favorable for the formation of tree rings. However, if the temperature continues to increase in June and July, reaching excessive values, it will urge trees to speed up their metabolism and increase their transpiration, which therefore limit their growth. Furthermore, the ring width has a very significant positive correlation with precipitation of September ($p<0.01$) and a significant positive correlation ($p <0.05$) with December of the previous season preceding growth and with April of the growing season (Fig. 4). With the increasing amount of rainfall during winter months especially December, soil water content is high and this may promote the development tree rings at the beginning of the spring season.

In June, with an increase of temperature and transpiration, the use of soil moisture by Cedar trees will become higher. This will engender rapid growth of rings, so the correlation between ring width and monthly precipitation will be somewhat positive in June and in the beginning of July. In August, due to high temperatures, monthly rainfall is significantly reduced; it means that the climate is therefore in the typical dry season of the Mediterranean climate. For this reason, the stock of water available to the trees is reduced and the rainfall becomes a major limiting factor for tree growth and this affected the growth of rings, therefore,

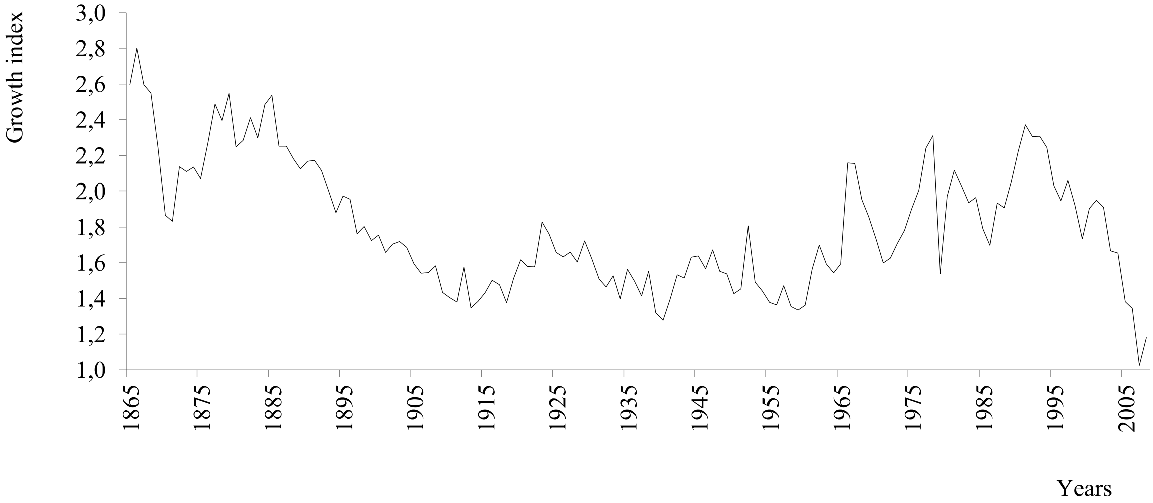

Figure 3. Mean chronology of indexed ring width

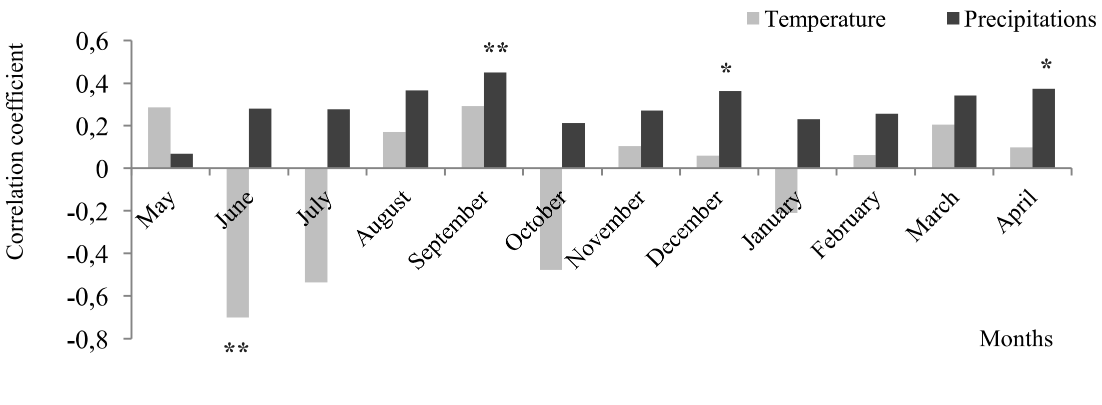

Figure 4. Correlations of the chronology of tree-ring widths with mean monthly temperatures and mean monthly rainfall of the period from May (year n) to April (year n+1) at the significance levels (**p<0.01 and *p<0.05)

the correlation between ring width and monthly rainfall is positively significant in August. The succession of a dry summer and a warm autumn may be unfavorable to the initiation of buds that should develop over the next year. Thus, the potential for growth for the next year will be seriously reduced.

Relationship between the mean temperature of June (1977-2008) and the width of rings

The results of the tree ring-climate relationship showed that the temperature has more impact on the chronology of Cedar than precipitation. In fact, the temperature of June is the most negatively and significantly correlated with the width of the rings (correlation coefficient = -0.731) at a significance level ($p<0.01$) compared to other months of the year (Fig. 5). This has been proved by the use of a linear regression, which indicates higher values of explained variance reaching 53.4% and a higher Fisher test value (F = 34.367) for temperatures than for precipitations, i.e. 20,4% and 7,699, respectively (Fig. 5). The tree ring width index ranged from 1.03 to 2.37 (with the average = 1.90 ± 0.33 for n = 32) and the average temperature of June is 23.82 ± 1.59 ° C (the range is 20.8-27.4 °C).

DISCUSSION

Basic statistical characteristics of the chronology of *Cedrus atlantica* tree rings

In the study area, the mean correlation coefficient between the trees (Rbar) is 0.789 (Tab.1) indicating a quite consistent radial growth, which is subject to the influence of the same environmental factors. This finding is similar to that reported by (Till 1987). The mean sensitivity primarily reflects changes of short-term and high-frequency climate (Wei & Fang 2008). In this study, this parameter reaches 0.251, while that of the Cedar forest of Jbel Lakraa (Rif) is only 0.08, showing an instability of the sensitivity of Cedar to climate change in this region (Till 1985). In the High and Middle Atlas Cedar forests, the sensitivity values are 0.44 and 0.296 respectively (Chbouki 1992, Ilmen *et al*. 2013). These values are somewhat higher than that of Bab Larz (0.251). On the other hand, reforestation stands of the Southeast of France showed similar values of sensitivity, ranging from 0.14 “La Verne” to 0.39 “Fontfroide” (Guibal 1984). Overall, the Cedar is sensitive to climatic fluctuations and constitutes an excellent biological memory to be exploited. Tree ring calculated parameters (SNR, EPS and VFE) are significant and indicate that the chronology of Atlas Cedar is rich of climate information and is suitable for ecological ring analysis.

Correlations between climatic parameters and growth indices over the period 1977-2008

The correlation between ring width climate variables (temperature and precipitation) is relatively high and so the confidence interval at the significance level (99% and 95%). Ring width of the Atlas Cedar is positively correlated with the mean monthly rainfall of the growing season, especially that of April. Indeed, autumn rainfall (October), the rainy winter and the relatively warm spring are responsible of the development of wide tree rings. These results agree with those of other authors (Fritts 1976 ; Kozlowski 1991). The fall and winter climate conditions, that enhance soil water content, favor the development and / or maintenance of the root system allowing ultimately a more efficient use of resources and accelerates the growth of rings (Riedacker 1976). In the study site, there was a positive influence of summer precipitation on radial growth, especially when climate conditions are more xeric. Also, the abundance of snow in winter (December-February) is not likely to delay the start of spring growth, because the southeast slope aspect of the study site promotes a faster melting of snow (Rolland 1995).

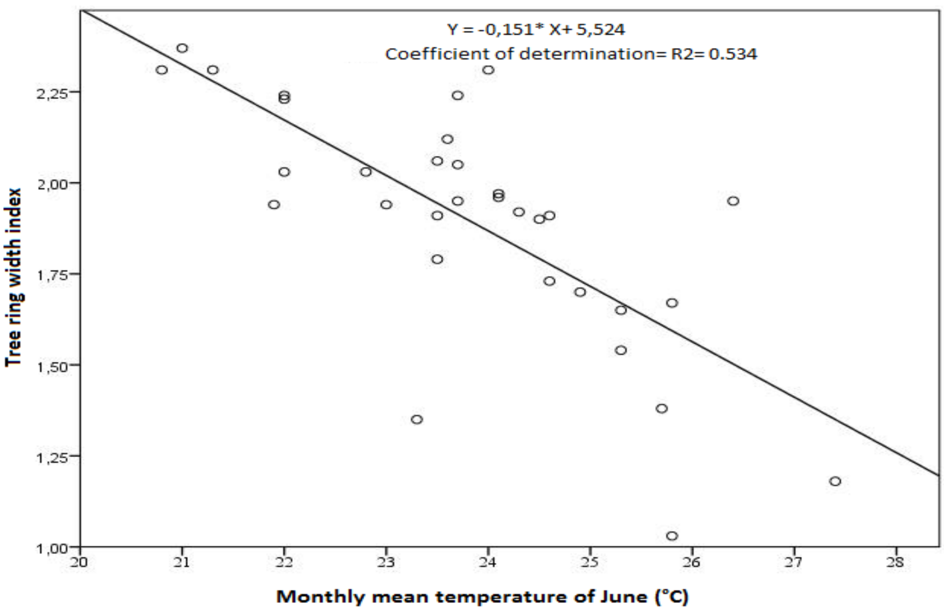

Figure 5. Relationship between tree ring width index of the Atlas Cedar and mean temperature of June from 1977 to 2008 in the Bab Larz site, Western Rif

The large growth, favored by the high temperatures of spring, is certainly related to the leaf development. It is known that the budding and leaf extension are highly dependent on thermal conditions, which favor their development (Lebourgeois *et al*. 2006b). The reafter, the drought conditions of summer influence negatively the growth of rings (reduced rainfall and / or high temperatures). The correlation between ring width and mean monthly temperatures is somewhat complicated. It is significantly negative in summer (June and July) and it becomes positive and less significant in September. These results are consistent with the ones reported by (Ilmen *et al*. 2013).

In some studies, August temperatures are shown to have a positive singular effect on tree growth because they promote the cellulose building at the expense of sugar and starch (Tranquillini 1979). They may also promote radial growth at the expense of other biological phenomenon which is more demanding to photosynthesis materials such cone production (Toth 1978, Till 1985). The results of the correlations between tree rings growth and temperatures, are different from those reported by Shao & Wu (1994), who found a positive effect of January temperatures for the Atlas Cedar, based on a response function calculated over the period 1941-1970. It should be noted that the study included populations of Cedar at altitudes ranging from 1400 to 2600 m (Shao & Wu 1994). While our analysis focuses on the period covering the second half of the 20th century and the early of 21st century and which temperature trend was characterized by a sharp rise, mainly since the 1970s according to climate records from rural meteorological stations implemented in the Middle Atlas region. These findings indicate that the requirements of Cedar to temperatures were relatively complex. So it appears that this would probably be due to the instability of the climate that caused a summer drought which may directly affect the normal growth of trees. Therefore, the understanding of the correlation between tree rings and climate on the basis of a single month is quite complicated as reported by (Bing & Peng 2012). Dendroclimatic analysis highlights the great effects of climate on Cedar growth. The relationship between tree rings growth and climate, demonstrates the ability of the Atlas Cedar to provide paleoclimatic informations.

CONCLUSION

The dendroclimatic study of the Atlas Cedar shows its sensitivity to temperature and rainfall conditions. The results of this study reveal information about the past and the present radial growth of Cedar stands, aged of 144 years and located at high altitudes of a sub-humid station in Western Rif, Morocco. Bab Larz Cedar exhibits some resistance to drought, but it needs more favorable thermic conditions. In fact, the mean radial growth and extreme growth years are somewhat more sensitive to summer and fall temperatures than precipitations which impact is positive especially during vegetation period. All these findings indirectly facilitate the understanding of the physiology of Cedar. Moreover, the use of appropriate climatic data, such as atmospheric humidity, evapotranspiration and insolation over biologically known intervals of time, is required for more detailed explanations.

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