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Climate impact on growth dynamics and intra-annual density fluctuations in Aleppo pine (*Pinus halepensis*) trees of different crown classes

J. Olivar [1,2], S. Bogino [3], H. Spiecker [2] &. F. Bravo [1]

[1] Sustainable Forest Management Research Institute, University of Valladolid-INIA. Avda. de Madrid 44, 34004 Palencia, Spain
[2] Institute of Forest Growth, Albert-Ludwigs-Universität Freiburg. Tennenbacherstr. 4, D-79106 Freiburg, Germany
[3] Departamento de Ciencias Agropecuarias. Facultad de Ingeniería y Ciencias Económico-Sociales. Universidad Nacional de San Luis. Avda. 25 de Mayo 384, 5730 Villa Mercedes, San Luis, Argentina
E-mail: jolivar@pvs.uva.es

Introduction

Tree radial-growth models are valuable for simulating the impacts of climate change on future growth of forest species. Understanding how forest growth responds to climate is a key element for a deeper knowledge of forest dynamics in a changing environment. Trees growing in extreme conditions respond strongly to climate variations (Fritts 1976). Mediterranean regions, as transitional climate zones between arid and humid regions of the world, are areas where climatic changes may have the greatest effects (Lavorel et al. 1998).

Different Mediterranean pine species have been analyzed to detect relationships between climatic trends and tree growth. *Pinus pinea* is positively correlated with precipitation in southern Portugal (Campelo et al. 2007). This fact has also been reported for *Pinus pinaster* in central Portugal (Vieira et al. 2009) and in central Spain (Bogino and Bravo 2008), for *Pinus nigra* in southeastern Spain (Martin-Benito et al. 2008) and for *Pinus sylvestris* towards its southern and western distribution limit (Bogino et al. 2009). Growth rate of *Pinus hapepensis* is sensitive mainly to temperature variations during the wet season and to soil humidity variations during the dry season in southern Italy (Attolini et al. 1990). In France, Rathgeber et al. (2005) concluded that *Pinus halepensis* growth is controlled by soil water availability during the growing season. In Greece, the growth of Aleppo pine is positively related with the winter and spring precipitations and negatively with the temperatures of the spring months (Papadopoulos et al. 2008).

Wood anatomical features in tree rings have been interpreted as indicators of environmental change (see for instance Briffa et al. 2003). Species growing under Mediterranean climate, with summer droughts and high inter-annual variability in precipitation and temperature, commonly show distinct anatomical characteristics in tree rings (Schweingruber 1993). Intra-annual density fluctuations (IADFs) are characterized by latewoodlike cells within the earlywood and earlywoodlike cells within the latewood (Fritts 2001). Consideration of IADFs in dendrochronological studies allows detailed analysis of climatic events within the growing season. Different studies of pine species showed a good correlation between IADF formation and climate in the Mediterranean area. IADFs were mainly correlated with precipitation in autumn in *P. pinaster* in Portugal (Vieira et al. 2009) and with precipitation in late winter and spring and higher temperatures in central Spain (Bogino & Bravo 2009). IADFs were caused by precipitation events early in summer following a water deficit early in the growing season in *Pinus pinea* in southern Portugal (Campelo et al. 2006). However, information about the impact of climate on IADFs of *Pinus halepensis* is scarce.

Aleppo Pine (*Pinus halepensis* Mill.) is a native pine of the Mediterranean region, where it is one of the main species in the present landscape. Therefore, the study of the impact of climatic variables (temperature and precipitation) on its radial growth is of major interest. The objectives of the present study were to identify relationships between radial growth and climate for different crown classes of Aleppo pine (*P. halepensis* Mill.), to quantify the presence of intra-annual density fluctuations (IADFs) according to crown class and cambial age and to establish the relationships between IADFs and climate.

Material and Methods

Eight sampling sites were selected throughout the natural distribution area of *Pinus halepensis* in the Iberian Peninsula (Fig. 1), and fifteen trees from each crown class (dominant and suppressed) were selected within each sampling site. Dominant trees were defined as those standing above all other trees in its vicinity and receiving full light from above, whereas suppressed trees were defined as those growing below the tree canopy.

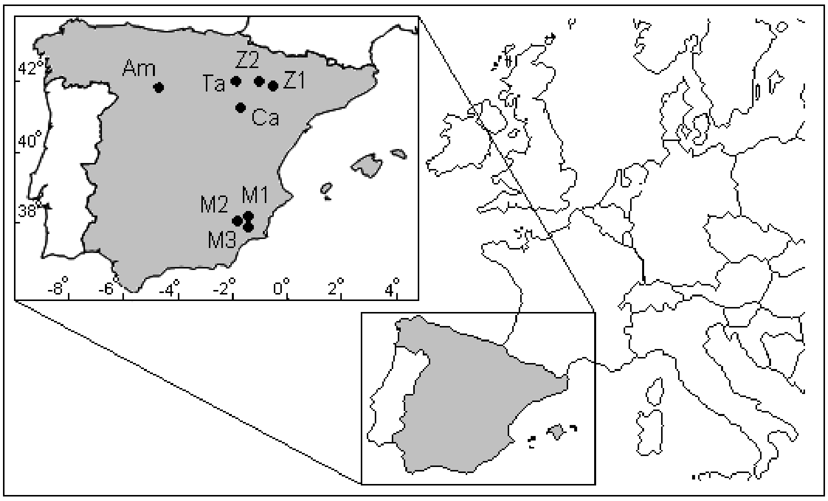

Figure 1: Study areas of Pinus halepensis in the Iberian Penninsula.

In sites Za1 and Za2 only dominant trees were sampled. Therefore, a total of fourteen tree-ring chronologies (eight dominant and six suppressed) were analyzed. From each tree two cores were extracted at 1.30 m above ground. The increment cores were air dried and mounted on wooden supports and dated according to standard dendrochronological techniques (Stokes & Smiley 1968). The preparation of the samples was done using a diamond flycutter (Kugler F500).

The program COFECHA (Holmes 2001; Grissino-Mayer 2001) was applied to assess dating accuracy. According to standard methods in dendrochronology trees exhibiting correlation values with the master chronology below 0.4 were excluded (Vieira et al. 2009).

To eliminate biological trends in tree-ring series and to minimize growth variations that are not common by most trees, the program ARSTAN (Cook and Holmes 1984; Holmes 2001) was used. Standardization removes geometrical and ecological trends while preserving inter-annual high-frequency variations that are presumably related to climate. To obtain a master chronology for each study site and crown class, the standardized series were averaged.

Chronology quality was evaluated using the signal-to-noise ratio (SNR), the proportion of the variability explained by climate or other casual factors divided by the residual or unexplained variability (Fritts & Swetnam 1989); and the expressed population signal (EPS), which indicates the degree to which the particular sample chronology portrays a hypothetically perfect chronology (Wigley et al. 1984).

Relationships between climatic data and tree-ring widths

Mean monthly temperature and total monthly precipitation were grouped in climatic seasons (winter, spring, summer and fall) and regressed against ring-width indices in order to assess climate-growth relationships. DENDROCLIM 2002 (Biondi & Waikul 2004) was applied to calculate correlation and response functions utilizing bootstrapped error estimates (Guiot 1991).

Intra-annual density fluctuations

Tree-rings were visually examined for IADFs. An IADF is defined as a layer of cells within a tree ring characterized by different shape, size and wall thickness (Kaennel & Schweingruber 1995). IADFs show a continuous transition in opposite to the annual rings boundary (Fritts 2001). Because of the variability of IADFs tangentially and vertically within the tree ring along the stem the IADFs were only considered when present in both cores, in the same tree ring.

As the number of samples changed over time, the relative frequency was calculated using:

[1] $F = n/N$

where F is the relative frequency of IADF in a particular year; n the number of trees that formed the IADF and N the total number of trees analyzed. Potential biases in the frequency were assessed by calculating the stabilized IADF frequency (f), according to (Osborn et al. 1997):

[2] $f = F^{0.5}$

Data analysis

The logistic equation form was chosen to model the probability of occurrence of IADFs [3]:

[3] $P = (1.0 + e^{(-z)})^{-1}$

where P is the probability of IADFs and $Z = b0+b1(x1)+b2(x2)+\ldots\ldots+bk(xk) + \varepsilon$; where x1; x2..... xk are the climatic variables and b0; b1; b2 ….. bk are unknown parameters of the model and ε is a normal random error N (0,1); and *e* is the exponential operator. The equation can be formulated to accept a binary variable such as occurrence of IADFs, and the parameters can be estimated by maximum-likelihood methods. The resulting prediction is bounded by 0 and 1. Monthly rainfall and mean monthly temperature were used as explanatory variables. The hydrological year was defined as a period of 12 months, from previous year October to current year September. A stepwise selection method was used to find the best model.

The alternative fits were evaluated on the basis of the Akaike criterion (AIC), the –2*Log Likelihood, the area under the receiver operating characteristic (ROC) curve and the expected behavior - as indicated by the signs of the estimated parameters. The ROC curve is displayed for the models and the area underneath was calculated as a value of the accuracy of the model. Values larger than 0.80 indicate an excellent discrimination (Hosmer & Lemeshow 2000). This curve relies on false/true positive/negative tests, and the sensitivity is indicated by the proportion of correctly classified events and the specificity by the proportion of correctly classified non-events (Hair et al. 1998). This model has previously been used to estimate the probability of occurrence of IADFs in *Pinus pinaster* subsp. *mesogenesis* in the Iberian Peninsula (Bogino & Bravo 2009a). The PROC LOGISTIC of SAS 9.1 (SAS Institute Inc. 2004) was used to fit the model. Samples were first grouped according to site location (Palencia, Aragón and Murcia), age (younger than 80 years and older than 80 years) and crown class (dominant and suppressed).

Results

The mean chronology of the suppressed trees showed slightly higher mean sensitivity values (0.30 for dominants and 0.33 for suppressed). However, in Ampudia dominant trees were more sensitive than suppressed trees. SNR values were also higher for dominants than for suppressed (26.64 and 12.77). The mean chronology of the dominant trees also showed higher variance and mean inter-series correlation values than the mean chronology of the suppressed trees (Tab. 1).

Table 1: Descriptive statistics of the dominant and suppressed chronologies. SD: standard deviation; MS: mean sensitivity; SNR: signal to noise ratio; EPS: expressed population signal; Var: variance in first eigenvector; and inter-series correlation (RBar): mean correlation among trees.

Social class	Period	Core number	Ring number	Age range	SD	MS	SNR	EPS	Var.	RBar
Dom.	1915-2008	22	1139	27-95	0.27	0.30	26.64	0.94	0.60	0.70
Suppr.	1917-2008	19	732	20-92	0.32	0.33	12.77	0.95	0.56	0.63

Precipitation appeared to be the main factor influencing tree growth with significant values in all seasons, while temperature reached only weak correlation values in two of the five seasons. Spring precipitation showed the most significant positive correlations followed by summer and winter previous to the growing season.

A total of 13502 tree rings were analyzed from trees from the eight sampling sites and a total of 107 IADFs were found. Samples were grouped according to site location, age and crown class. The percentage of trees with IADFs was rather similar for young and old stands. However, the percentage of IADFs and the stabilized IADF were higher for young stands than for old stands. The percentage of trees with IADFs and the percentage of IADFs were both higher for suppressed than dominant trees. Mean stabilized IADF was the same for both crown classes.

IADF frequency in relation to calendar year showed an increase in IADFs from the 1980s to the present. 1983, 1989, 1995 and 1999 were the years with more IADFs, with a stabilized frequency higher than 0.2. The nonlinear logistic equation form was chosen to model the probability of occurrence of IADFs with monthly precipitation and mean monthly temperature as variables.

The logistic function estimated that 10 monthly climatic variables out of 24 had a significant effect on predicting future IADFs. The model showed that, without considering crown classes, precipitations in October, December, March, April, June and mean monthly temperatures in June and September had a positive impact on the formation of IADFs, while precipitations in November and July and mean monthly temperatures in May had a negative impact on the formation of IADFs. December and April precipitation totals had a positive impact on the formation of IADFs in both dominant and suppressed trees, while precipitations in July had a negative impact. The area underneath the ROC curve was 0.918 for all trees, 0.917 for dominant trees and 0.943 for suppressed trees. The accuracy of the model is also sufficient to use it to predict occurrence of IADFs.

Discussion

Pinus halepensis shows significant correlations between trees growing at the same site, high expressed population signals and accurate statistical values suggesting a clear response to environmental factors. In addition, it confirms the tendency of Mediterranean species to develop diagnostic anatomical structures (Schweingruber 1993). We found common radial growth patterns among dominant and suppressed series in the same site. These results agree with previous studies in the Iberian Peninsula suggesting that pine species growing in the southern dendroecological section contain a common growth response to environmental factors (Richter et al. 1991; Bogino & Bravo 2008).

Descriptive chronology statistics suggest that the tree-ring series reflect one or more associated factors (including climate), and a strong response of radial growth to changes in climatic conditions as indicated by the mean sensitivity values (MS) from 0.21 to 0.40 that are higher than the 0.16 to 0.34 values found in previous studies on pine species (*Pinus sylvestris* L., *Pinus nigra* Arnold, *Pinus pinaster* Ait. and *Pinus mugo* ssp. *uncinata* Turra.) in the Iberian Peninsula (Richter et al.

1991; Bogino & Bravo 2008; Martin-Benito et al. 2008; Bogino & Bravo 2009; Bogino et al. 2009; Vieira et al. 2009).

The expressed population signal (EPS) ranging from 0.89 to 0.98 is in all cases higher than the critical level of 0.85 suggested by Wigley et al. (1984), which implies that the chronologies are representative of regional tree growth. First eigenvector variance indicated good homogeneity within the same site. It can be concluded that the fourteen mean chronologies have high MS, SNR, EPS and percentage of the variance accounted for by the first eigenvector, suggesting a strong common signal associated with climatic factors.

The results show that *P. halepensis* growth is mainly controlled by precipitation. Previous studies reported that growth of Aleppo pine is controlled by soil water availability (Rathgeber et al. 2005) and precipitation is the main factor influencing tree growth of pine species in semiarid Mediterranean regions (Raventós et al. 2001). Winter previous to the growing season and current year spring precipitation are positively correlated with tree-ring growth. Similar results were found in the Attica basin (Greece) (Papadopoulos et al. 2008). Other Mediterranean pine species support this conclusion: growth of *Pinus pinea* in a dry Mediterranean area in Portugal, *Pinus pinaster* in central Spain and *Pinus sylvestris* at its southern distribution limits were positively correlated with rainfall (Campelo et al. 2006; Bogino & Bravo 2008; Bogino et al. 2009). Growth of *Pinus nigra* in central Spain and *Pinus pinaster* in Portugal were mainly influenced by May precipitation (Martin-Benito et al. 2008; Vieira et al. 2009).

We found a higher tendency in young stands for developing IADFs. These results corroborate previous dendroecological studies, which suggested that IADFs were more frequent in younger tree rings (Rigling et al. 2001; Villalba & Veblen 1994; Vieira et al. 2009; Bogino & Bravo 2009). This could be due to a faster response of young trees to changing factors (Villalba & Veblen 1994) and/or to a longer growing season of young trees (Rossi et al. 2008). Since young trees have a different response to environmental factors than old trees, the incorporation of age-dependent differences on the appearance of special ring features such as IADFs and their association to climatic variables provides a useful proxy for complementing dendroclimatological data. In addition, these parameters can support to predict differences on how young and old trees react to climate change. As it was previously reported (Bogino & Bravo 2009) higher IADF frequencies occurred in the most recent fifty years. The increase in drought events in the Iberian Peninsula (IPCC 2007) may explain the higher IADF frequency during this period.

The occurrence of IADFs in *Pinus halepensis* was positively correlated with precipitation in December and April and negatively correlated with precipitation in July. These results are consistent with those of previous studies in *Pinus pinaster* in central Spain, where IADFs were mainly correlated with rainfall pulses in late winter and spring (Bogino & Bravo 2009). IADFs correlated positively with precipitation events early in summer following a water deficit early in the growing season in *Pinus pinea* in southern Portugal (Campelo et al. 2006), which is consistent with the present results that showed precipitation in July to have a negative effect on IADFs. Favourable climatic conditions in winter and spring as well as water deficits early in the growing season followed by rainfall indicate an increase in the probability of the occurrence of IADFs. This corroborates that growth may temporarily stop, but is always ready to resume activity as soon as climatic conditions become favourable.

Winter precipitation preceding the formation period of the tree-rings as well as the spring rainfall at the beginning of the growing season play a prevailing role to the development of wider tree rings in P. halepensis (Papadopoulos et al. 2008). These climatic conditions also appear as favourable conditions for the formation of IADFs in our study, supporting previous findings that showned IADFs to be more frequent in wider tree-rings (Vieira et al. 2009; Rigling et al. 2001; Villalba & Velben 1994).

Conclusions

Pinus halepensis is an accurate species for tree-ring analysis with good correlations between trees growing at the same site and a clear response to environmental factors. Suppressed trees showed higher sensitivity than dominant trees, with greater growth rates during favourable years except for Ampudia, where dominant trees showed higher sensitivity than suppressed trees. Precipitation was the main factor influencing tree-ring growth. IADFs were more frequent in young than in old stands with no clear differences according to crown classes. A higher frequency in IADFs occurred in the last fifty years, which coincides with the increase in drought events in the Iberian Peninsula. The probability model used, showed that high precipitation in spring and winter indicates an increase in the probability of the occurrence of IADFs, while high precipitation in July indicates a decrease in the probability of the occurrence of IADFs in Aleppo pine trees growing under Mediterranean climate conditions.

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References

Attolini, M. R., Calvani, F., Galli, M., Nanni, T., Ruggiero, L., Schaer, E., Zuanni, F. (1990): The relationship between climatic variables and wood structure in *Pinus halepensis* mill. *Theoretical and Applied Cimatology* 41: 121-127.

Bogino, S., Bravo, F. (2008): Growth response of *Pinus pinaster* ait. to climatic variables in central Spanish forests. *Annals of Forest Science* 68: 506-518.

Bogino, S., bravo, f. (2009): Climate and intra-annual density fluctuations in *Pinus pinaster* subsp. Mesogeensis in Spanish woodlands. *Canadian Journal of Forest Research* 39 (8): 1557-1565.

Bogino, S., Fernández Nieto, M. J., Bravo F. (2009): Climate effect on radial growth of *Pinus sylvestris* at its southern and western distribution limits. *Silva fennica* 43(4): 609-623.

Bréda, N., Huc, R., Granier, A., Dreyer, E. (2006): Temperate forest trees and stands under severe drought: a review of ecophysiological response, adaptation processes and long-term consequences. *Annals of Forest Science* 42: 206-219.

Briffa, K. R., Osborn, T. J., Schweingruber, F. H. (2003): Large-scale temperature inferences from tree rings: a review. *Global and Planetary Change* 40: 11-26.

Campelo, F., Nabais, C.; Freitas, H., Gutiérrez, E. (2007): Climatic significance of tree-ring width and intra-annual density fluctuations in *Pinus pinea* from a dry Mediterranean area in Portugal. *Annals of Forest Science* 64: 229-238.

Cook, E. R., Holmes, R. L. (1984): Program Arstan users manual. Laboratory of tree ring research, University of Arizona, Tucson, USA.

Fritts, H.C. (1976): Tree rings and climate. Academic Press, London.

Fritts, H. C., Swetnam, T. W. (1989): Dendroecology: a tool for evaluating variations in past and present environments. *Advances in Ecological Research* 19: 111-188.

Fritts, H. C. (2001): Tree rings and climate. The Blackburn press, London.

Grissino-Mayer, H. D. (2001): Evaluating crossdating accuracy: a manual and tutorial for the computer program Cofecha. *Tree-ring Research* 57: 205-221.

Hair, j. E., Anderson, R.E., Tatham, r. L., Black, W.C. (1998): Multivariate data analysis. 5th ed. Prentice Hall, Upper Saddle River, New Jork, Usa.

Hosme,r D. W., Lemeshow, S. (2000): Applied logistic regression. John wiley & sons inc., 375 pp.

Holmes, R. L. (2001): Dendrochronology program library. Laboratory of tree ring research, University of Arizona, Tucson, USA.

IPCC 2007. Fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kaenel, M., Schweingruber, F.H. (1995): Multilingual Glossary of Dendrochronology. Paul Haupt publishers Berne, Stuttgart, Vienna.

Lavorel, S., Canadell, J., Rambla, S., Terradas, J. (1998): Mediterranean terrestrial ecosystems: research priorities on global change effect. *Global Ecology and Biogeography Letters* 7: 157-166.

Martin-Benito, D., Cherubini, P., del Rio, M., Cañellas, I. (2008): Growth response to climate and drought in *Pinus nigra* arn. Trees of different crown classes. *Trees* 22: 363-373.

Montero, G., Cañellas, I., Ruíz-Peinado, R. (2001): Growth and yield models for *Pinus halepensis.* Mill. *Investigaciones Agrarias: Sistemas y Recursos Forestales* 10 (1): 179-201.

Osborn, T.J., Briffa, K.R., Jones, P.D. (1997): Adjusting variance for sample-size in tree-ring chronologies and other regional mean time series. *Dendrochronologia* 15: 1-10.

Papadopoulos, A., Tolica, K., Pantera, A., Maheras, P. (2008): Investigation of the annual variability of the Aleppo pine tree-ring width: the relationship with the climatic conditions in the Attica basin. *Global Nest Journal*.

Raventós, J., de Luís, M., Gras, M., Cufar, K., González-Hidalgo, J., Bonet, A., Sánchez, J. (2001): Growth of *Pinus pinea* and *Pinus halepensis* as affected by dryness, marine spray and land use changes in a Mediterranean semiarid ecosystem. *Dendrochronologia* 19: 211-220.

Rathgeber, C., Misson, L., Nicault, A., Guiot, J. (2005): Bioclimatic model of tree radial growth: application to French Mediterranean Aleppo pine forests. Trees 19: 162-176.

Richter, K., Eckstein, D. Holmes, R. L. (1991): The dendrochronological signal of pine trees (*Pinus spp.*) in Spain. *Tree-ring Bulletin* 51: 1-13.

Rigling, A., Waldner, P. O., Forster, T., Bräker O. U., Pouttu, A. (2001): Ecological interpretation of tree-ring width and intra-annual density fluctuations in *Pinus sylvestris* on dry sites in the central Alps and Siberia. *Canadian Journal of Forest Research* 31: 18-31.

Rigling, A., Braker, O., Schneiter, G., Schweingruber, F. (2002): Intra-annual tree-ring parameters indicating differences in drought stress of *Pinus sylvestris* forests within the Erico-Pinion in the Valais (Switzerland). *Plant Ecology* 163: 105-121.

Rossi, S., Deslauriers, A., Anfodillo, T., Carrer, M. (2008): Age-dependent xylogenesis in timberline conifers. *New Phytologist* 177: 199-208.

Sas Institute inc. (2004): Sas/stat versión 9.1, user's guide. Cary, nc, usa.

Schweingruber, F. H. (1993): Trees and wood in dendrochronology. Springer series in 324 wood science, Springer-Verlag.

Stokes, M., Smiley, T. (1968): An introduction to tree-ring dating, University of Arizona press, Tucson, USA.

Vieira, J., Campelo, F., Nabais, C. (2009): Age-dependent responses of tree-ring growth and intra-annual density fluctuations of *Pinus pinaster* to Mediterranean climate. *Trees* 23: 257-265

Villalba, R., Veblen, T. T. (1994): A tree-ring record of dry spring wet summer events in the forest-steppe ecotone northern Patagonia, Argentina. In: dean js, meko dm, swetnam tw (eds) tree rings environment and humanity. Radiocarbon, spec. Issue: 107-116.

Wigley, T. M. L., Briffa, K. R., Jones, P. D. (1984): On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Applied Meteorology and Climatology* 23: 201–213.