Impact of climate change on pines forest productivity and on the shift of a bioclimatic limit in Mediterranean area

Vennetier M., Vilà B., Liang E., Guibal F., Taahbet A., Gadbin-Henry C.

in

Leone V. (ed.), Lovreglio R. (ed.).
Proceedings of the international workshop MEDPINE 3: conservation, regeneration and restoration of Mediterranean pines and their ecosystems

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 75

2007
pages 189-197

IMPACT OF CLIMATE CHANGE ON PINES FOREST PRODUCTIVITY AND ON THE SHIFT OF A BIOCLIMATIC LIMIT IN MEDITERRANEAN AREA

M. Vennetier*, B. Vila, E. Liang***, F. Guibal**, A. Taahbet*,** and C. Gadbin-Henry****

*Cemagref, UR Ecosystèmes Méditerranéens et Risques, Aix en Provence

**Institut Méditerranéen d'Ecologie et de Paléoécologie (IMEP),CNRS UMR 6116, Marseille

***Institute of Tibetan Plateau Research, Chinese Academy of Sciences Beijing, Chine

SUMMARY - *This paper deals with the impact of climate change on the productivity of Pinus halepensis and Pinus silvestris in the French Mediterranean area and the shift of the bioclimatic limit between theses two pines. It also gives some of the main synthetic results of this research, based mainly on dendroecology. The experimental design includes a series of plots distributed along an altitudinal transect on the north slope of Sainte-Baume mountain. The choice of the site, homogeneous for rainfall regime, as well as the homogeneity in substrata, soil and topography at the level of plots, allows to focus on the variations of the response of trees due to differences in mean annual temperatures. Additional plots with soils much deeper or much shallower than those of the main transect also allow studying the interaction between climate and soil water balance on the growth of trees. The impact of the exceptional scorching heat and drought of year 2003 is also analyzed. The response of trees to monthly climatic parameters depends a lot on the annual mean temperature and soil water balance. The climate warming should thus produce significant effects on the short-term on forest productivity. While the productivity of the Pinus halepensis strongly increased during the 20th century, that of Pinus silvestris decreased strongly in the same period. Year 2003 reduced directly the growth of these pines. But, especially by its detrimental delayed effects on their health status and their leaf area, it limits their potential growth for several following years. The productivity of these two pines should be reduced strongly in the next decades. Many withering stands observed in Pinus silvestris distribution area since 2003 show that the survival of large areas of this species is threatened in the short or middle term by climate warming in the French Mediterranean region.*

Keywords: climate change, *Pinus halepensis*, *Pinus silvestris*, forest productivity**,** dendroecology, drought, scorching heat, year 2003

INTRODUCTION

Many corroborating research results show an acceleration of tree growth during the 20^{th} century in the Northern hemisphere (Diaz *et al.*, 1997). In Europe, an increase of the annual average growth of trees was noted, whatever the silvicultural treatment, for most of the forest species (Spiecker *et al.*, 1996). In France, the phenomenon was noticed on *Abies alba* Mill and *Picea abies* (L.) Kars. (Bert, 1992; Becker *et al*., 1994 a), *Fagus sylvatica* L. (Badeau., 1995; Picard, 1995) and on deciduous oaks (Becker *et al.*, 1994 b).

For the Mediterranean area, studies tackling tree growth variations are fewer than in the rest of France and Europe. An acceleration of radial growth was noticed for *Quercus pubescens* Willd. (Rathgeber et al., 1999), *Pinus laricio* Poir. (Lebourgeois and Becker, 1996), *Larix decidua* Mill. (Belingard *et al.*, 1996). Results obtained by IMEP showed that significant variations of the radial growth occurred in stands localized at the very limit of species distribution area (Keller et al., 1997 a and b; Rathgeber et al., 2000 a and b). For height growth, several studies by Cemagref showed an acceleration, during last decades for *Cedrus atlantica* (Endl.) Carrière (Ripert and Boisseau, 1993), *Pinus laricio* Poir. (Nouals and Boisseau, 1992), *Pinus silvestris* L., (Vila *et al.*, 2001) and over more than 80 years for *Pinus halepensis* Mill. (Vennetier and Hervé 1999).

The scientific community agree to interpret these growth variations as the result of several major changes in the environment, and particularly:

- climate change (Herdsman, 1992; Ramaswamy, 2001) related to the increase of the concentration of greenhouse effect gases among which CO2, (Prentice, 2001; Keeling and Worf, 2001),
- a direct fertilizing effect of the atmospheric CO2 (Kirsbaum and Fischlin, 1996),

- nitrogen deposition from the atmospheric pollution, (Nellemann and Thomsen, 2001)
- soil recovery with the giving up of overexploitation practices (Gladzel, 1999),
- and as a combination of these factors.

The Mediterranean climate is characterized by a summer drought, which is the main constraints for the vegetation (Daget, 1977) and which could become critical with the foreseen climate change (Hoff and Rambal, 2000). The succession of very warm years since 1998, with the paroxysm in 2003, seems to have harmed the vegetation in France (Pauly and Belrose, on 2005), including in Mediterranean region.

In this paper, we present some results of a study aiming at assessing the impact of long term climate change and the exceptional drought and heat of year 2003 on the productivity, health status and bioclimatic limit of *Pinus halepensis* and *Pinus sylvestris*. These species are the main conifers of the French Mediterranean area, dominating respectively the coastal area at low elevation and the hinterland.

MATERIAL AND METHODS

We set up a specific experimental design (Fig. 1) based upon a short transect along the homogeneous north slope of the Sainte-Baume Mountain, South-Eastern France. On this slope, *Pinus halepensis* and *Pinus silvestris* are mixed in a very narrow strip at the very limit of their respective distribution area. This site was perfect to study the shift of the limit between these distribution areas.

All the plots along the transect (8 for *Pinus halepensis*, 7 for *Pinus sylvestris*) were laid out on the same type of soil, derived from a thick and hard rock layer: calcareous pouddingstone for most plots, and limestone for a few plots at the foot and top of the mountain. They are based on an alteritic horizon, locally covered by a thin colluvial horizon. Their texture is balanced between clay and silt, with sometimes a reduced sand fraction. All the plots have the same aspect, with a slight slope facing the north and all are characterized by a medium global water balance index according the model developed by the CEMAGREF (Ripert and Vennetier, 2002).

This experiment allowed analysing the variations of productivity and health status of tree species *versus* the changes in temperature, by eliminating most of the variations in rain patterns and site conditions. The influences of site conditions were however simultaneously taken into account by a complementary experimental design, based on additional plots at several positions along the main transect with 3 contrasted levels of water balance (ABC).

The direct impact and delayed effects of 2003 scorching heat and drought were studied on the same plots, and helped improving the interpretation of long-term trends and climate-growth models. This follow-up included stands of *Pinus pinaster, Pinus pinea* and *Cedrus atlantica* on a limited number of plots (Fig. 1).

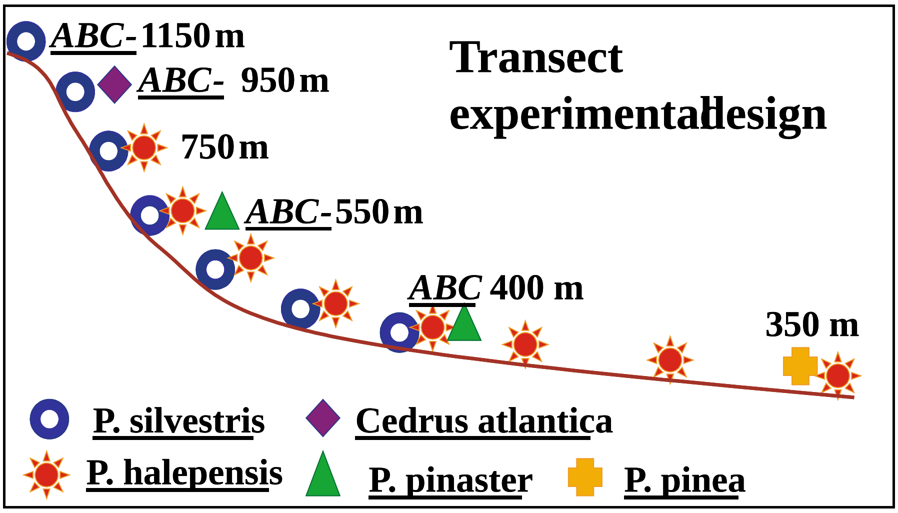

Fig. 1. Transect on the north slope of Sainte-Baume Mountain. Plots of the main transect are chosen at the same level of fertility and water balance. At 4 different elevations, additional plots are chosen at 3 contrasted levels of water balance (ABC).

We used dendroecology as main scientific approach for the assessment of forest productivity. Three cores were taken from trees on each plot at several dates from 2001 to 2005. Ring width was measured and indexed with standard methods (Fritts, 1976).

Data analysis and climates-growth relations modelling used on one hand, standard methods of dendroecology as response functions (Guiot, 1982), on the other hand, innovative methods as PLS regression and neuronal networks.

The relative variations of productivity of the plots were calculated and compared after elimination of age related trends. For that purpose, a general trend of the evolution of trees productivity with the age for each species was calculated from all the plots of IMEP and Cemagref data bases (more than 700 trees of all ages). This general trend was removed from the trend of each plot of this experiment, to focus on the local specific trend (Vila and Vennetier, 2003).

Health status was assessed with a health index based on 5 classes of crown transparency and needle colour, and the observation of the percentage of living needles on yearly shoots for the last 5 years.

RESULTS

Methodological approach

Sainte-Baume experimental design demonstrated the interest of this type of device to assess the variability of the response of species and their adaptability according to the temperature gradient and to the water balance. At a given elevation, the response to climate for the two pine species depends of the local water balance *(Fig. 2)*.

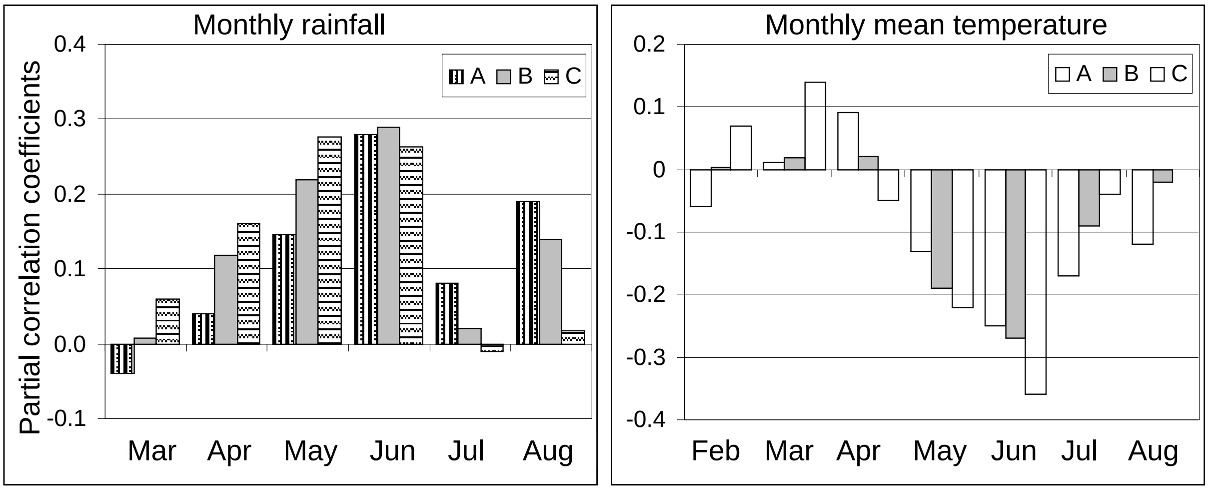

Fig. 2. Variations of the response of Pinus silvestris radial growth to the climate (elevation 900 m) according to sites' water balance: A = favourable, B = mean, C = unfavourable. (Ordinate axis: partial correlation coefficients of the monthly climatic parameters in the PLS regression which is the base of the model)

In sites characterized by unfavourable water balance, trees are sensitive to rains in the beginning of spring because they do not benefit for a long time from reserves accumulated in winter. In dormancy from the beginning of summer, trees are not sensible to the climate of summer and autumn. In sites characterized by favourable water balance, where soil and topography allow to take advantage for a long time of water reserves from winter rains, tree growth depends less on the first spring rains and can continue in the beginning of summer. It could grow again after a short summer break when the end of summer is favourable.

The analysis of plots results by sliding average demonstrated variations of trees response to climate according to the temperature gradient along the slope. Figure 3 shows that these variations of the response to climatic variables (monthly rains and temperatures) follow regularly the temperature gradient and that they are visible for small variations of the elevation: the difference between the average elevation of the extreme groups is only 300 m, corresponding to a variation of 1.8℃ of annual mean temperature. The difference between nearby groups is less than 100 m.

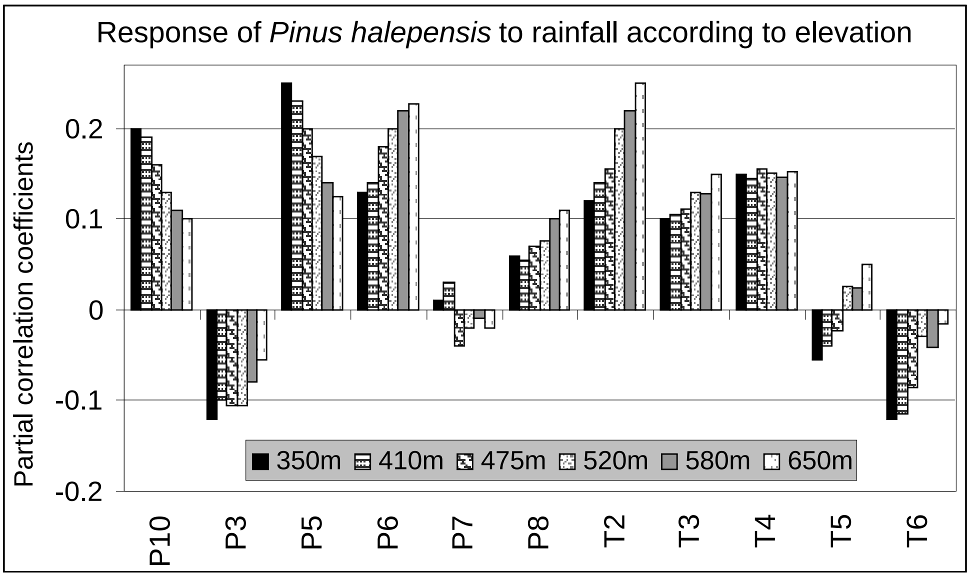

Fig. 3. Response of Pinus halepensis radial growth to monthly climatic parameters (rainfall = P, temperature = T, figure = n°of the month - eg: P6 = rains of June) according to the elevation, for an average site water balance (B plots). The elevation represents the sliding average of 3 successive plots. (Ordinate axis: partial correlation coefficients of the monthly climatic parameters in the PLS regression which is the base of the model).

Small variations in the annual mean temperature induce significant variations in the response of trees. We can conclude that climate warming may modify very quickly the behaviour of trees, as the monthly average temperatures on the study area increased about 1℃ during the 20th century, and the current scenarios of climate evolution foresee several supplementary degrees in the next 50 years.

Productivity of both pine species

The growth of *Pinus halepensis* accelerated during the 20th century, whatever the elevation and the site water balance, whereas that of the *Pinus silvestris* decreased strongly between 700 and 1500 m in elevation **(**Vila *et al*., 2005**)** (*Fig. 4*).

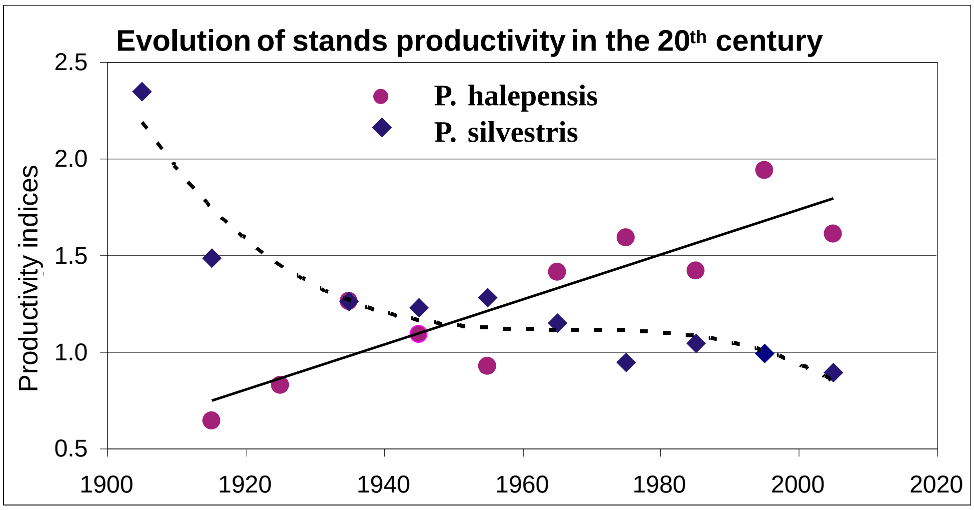

Fig. 4 Evolution of the of productivity indices of P. halepensis and P. silvestris during the 20th century. Irregularities of the trend for P. halepensis are due to deep frosts in 1956 and 1985-87. Those of P. silvestris are due to snow break, particularly in 1973 and 2001. A decline is observed since 1999 for both species, due to a series of dry years, snow breaks and to the scorching heat of 2003.

Surprisingly, the productivity of *Pinus sylvestris* at the lowest elevations (< 700 m), very low initially, remained stable or increased during the 20th century. This specific response has probably, at least partly, a genetic origin (Ledig, 1998). These trees were genetically naturally selected since several generations in a context of frequent droughts and high temperatures. They are also, from their birth, morphologically adapted to these extreme conditions for the species: high root/crown biomass ratio, small height (Larcher, 1995). Thus, they would have better withstand the climate warming than the trees living at higher elevation, that were born and have been living for several generations in a cooler and more humid climate. On the other hand, these trees particularly suffered extreme temperatures of year 2003, what demonstrates that in this occasion, a critical temperature threshold was exceeded for the species in spite of its relative local adaptation.

Tree rings-climate models

Models connecting climatic variables and tree rings were established for each of the plots over the period 1900-1998. Combining these models allows to interpret and to predict the variations of the radial growth of trees according to the environment: monthly and annual climatic variations, exceptional climatic events, local water balance, and elevation gradient. The extrapolation of these models allows predicting growth and productivity trends according to scenarios of climate change.

We tested them on the basis of a scenario supplied by the French National Meteorological Research Centre in 2000 (IPCC 2B regionally interpolated), predicting an increase of 2.5℃ of the average temperature in the 21st century (Fig. 5).

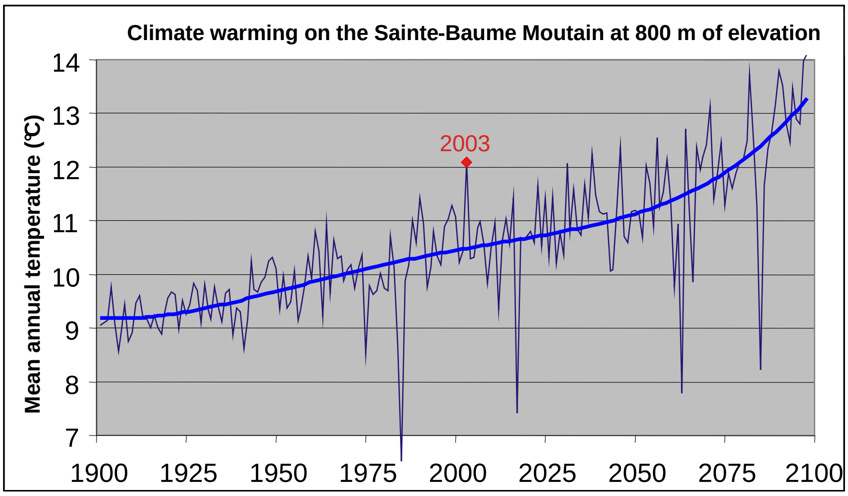

Fig. 5. Expected evolution of annual mean temperature on Sainte-Baume Mountain at 800 m of elevation according to IPCC 2B scenario.

Two examples of the evolution of the productivity are presented in the figure 6. For these figure, the real climate of the years 1999 to 2005, which was not available during the study, was simulated by the model. In fact, this last period was very unfavourable and led to a reduction of the productivity even for *Pinus halepensis* (Fig. 6).

For *Pinus silvestris* a constant decrease of the productivity was noticed with a collapse from the middle of the 21st century. Curves are similar whatever the elevation. For *Pinus halepensis* we noticed a continuation of the increasing trend in the first decades of the 21st century, reversing to end in a strong reduction in the 2nd half of the century. The curves had the same shape at all elevations, but the decline was a bit sharper at the lowest elevations.

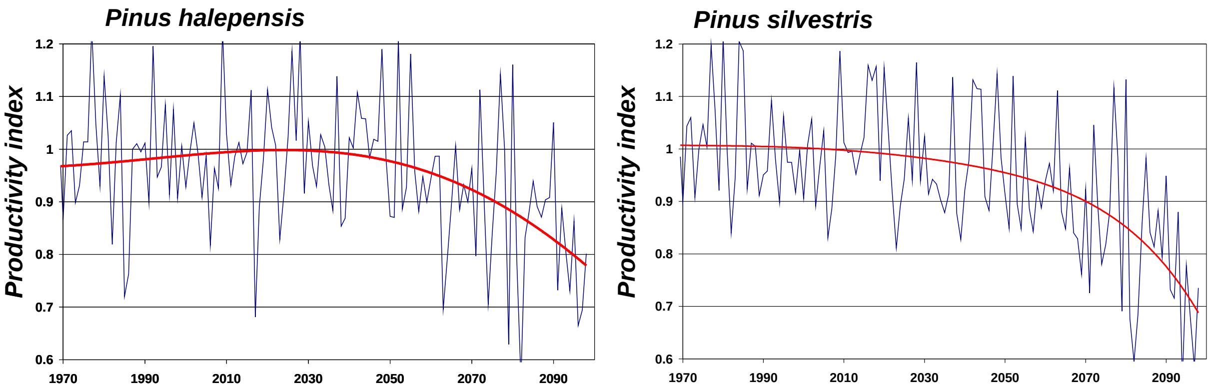

Fig. 6. Simulated evolution of Pinus halepensis and Pinus silvestris productivity between 1970 and 2100. 1 is a relative reference by species. The productivity of Pinus silvestris is today 2 to 3 times lower than that of Pinus halepensis at the same elevation.

Impact of the scorching heat of year 2003

The scorching heat of year 2003 gave us the opportunity to study the response of well known stands of our experimental design in Sainte-Baume Mountain. It was also important to assess the reliability of our models, comparing their simulations of ring width with the measured data from years following 1998, particularly those of 2003. It was finally important to take advantage of 2003 to introduce into the models the unpredictable impact of that unprecedented event, as this scorching heat gave a good idea of what could be the average climate in the middle of the 21st century (Fig. 5).

The first results of this study showed that year 2003 was not so bad for diameter growth, as predicted by models. Earlywood growth began at the end of the winter in the Mediterranean region, rings were already broad in May, when trees started to be stressed by high temperature and water shortage. But the latewood, depending on the climate of the end of the spring, was very narrow, with a low density and was even sometimes absent.

Trees suffered a lot during summer 2003. Conifers lost a strong proportion of their needles (Fig.7). Leaves fall in the middle of august for most of the species, including some evergreen species. So that the strongest negative impact on the growth was noticed in 2004. A peak of mortality occurred in spring, 2004 particularly for *Pinus silvestris*.

In 2005, extensive die back was observed in *Pinus silvestris stands* below 1500 m of elevation: either by whole stands of several hundreds of hectares on shallow or marly soils in the Southern-Alps, or scattered but in strong proportion (up to 30 % of the adult trees and 70 % of the regeneration) on Sainte-Baume mountain whatever the soil. Many small stands at the lowest elevation completely died.

The measure of rings elaborated in 2004 showed that this ring is often as narrow as that of 2003. According to the first measures, the ring of 2005 is very variable, representative of the variable health status of trees. At the end of 2005, most of the Mediterranean pines still show a strong deficit of needles. This underlines the long lasting delayed impact of the year 2003.

Fig. 7. "Transparent" crowns of young Pinus halepensis at the end of 2004 and detail of a top. Needles remain only on the shoot of 2004 and sometimes on the shoot of 2003) instead of 3 to 5 last years usually. The leaf area and thus the growth are reduced for several years.

DISCUSSION

The bioclimatic limit between Pinus silvestris and Pinus halepensis

The climate change clearly weakens *Pinus silvestris* since some decades in the Mediterranean part of its distribution area, so that it can no longer compete with *Pinus halepensis* and *Quercus pubescens* in mixed stands (Rathgeber *et al.*, 1999).

According to Quézel and Médail (2003), global change should induce an altitudinal shift from one vegetation stage to another over the Mediterranean basin. The theoretical limit between these two species should quickly shift in elevation and in latitude with climate warming and the repeated droughts. This hypothesis is confirmed by our field observations: 20 years old *Pinus halepensis* can be found around 1000 m of elevation on Sainte-Baume Mountain, that is 200 m higher than the old stands and than the limit of the species given by past surveys. At the same time, *Pinus silvestris* is disappearing from the lowest elevations and its growth slows down in remaining stands.

But the physical limit between these species should not shift as fast as the theoretical limit, except on the steep slopes where the two species are already mixed. Given the short distance of dissemination of the pine it would be impossible for *Pinus halepensis* to fill naturally, during the next century, the gaps created in the Mediterranean mountains, far from its actual populations, by withering stands of *Pinus silvestris*.

Disruption in ecosystems

We can consider *Pinus silvestris and Pinus halepensis* as models, representing respectively supra and meso-Mediterranean bioclimates. In these bioclimatic areas, all the species are experiencing the disruption of their survival and growth conditions. A relation can be established between the growth of some trees and the production of herbaceous biomass (Liang *et al.*, 2003). In 2003, many shrubby species in the undergrowth and in matorals showed high mortality rates. The reduction of leaf area in the canopy and trees die back leads to a new balance between low and high strata of the vegetation, and in a modification of the forest microclimate.

Major changes should thus impact the forest ecosystems, especially because the last scenarios of climate change foresee a faster warming than the one we used during this study. But because of the complex interactions between climate and soil in forest productivity, because of the slowness of species dispersal and growth of the main forest species, because we know very few about the competition between species in the natural stands, and because we do not know the capacity of natural genetic adaptation of trees, these changes remain still unpredictable.

Economically, the impact of the reduced growth and the predictable partial or total die back of *Pinus silvestris* in the next decades is potentially important in the French Mediterranean area, as this species is dominant in surface, volume and production in this region.

CONCLUSION AND PROSPECTS

The analyses of direct and delayed effects of year 2003 must be continued to improve the climate-growth models. The first results showed that year 2003 will have unfavourable consequences on the growth and the health status of pines stands during several years, and that our present assessment of forest productivity for the 21st century must be revised downward.

The extensive die back observed since 2003 has to be the highlighted, and to be compared with similar phenomena occurring in other parts of the northern hemisphere, notably in the United States where millions of hectares are at risk after a similar drought and scorching heat in 2002. This die back cannot be predicted by growth models but must be taken into account in those models and assessed separately with thresholds analyses. We think that *Pinus silvestris*, already in trouble at present, could hardly survive in the climate foreseen in Mediterranean regions at the end of the 21st century and even well before.

On the ecological point of view, additional work is necessary on the response of shrubs and herbaceous species. From a methodological point of view, our approach by local transects, to study the response of species at the very limit of their distribution area could be adapted to many species and regions as a complement to the large national or international observation and experimental design.

BIBLIOGRAPHIE

Badeau V., 1995. Etude dendroécologique du hêtre (*Fagus silvatica* L.) sur les plateaux calcaires de Lorraine. Influence de la gestion sylvicole. Thèse de Doctorat, Université Henri-Poincaré, Nancy I, 205 p.

Becker M., Bert G.D., Bouchon J., Picard J.F., and Ulrich E., 1994 a. Tendances à long terme observées dans la croissance de divers feuillus et résineux du Nord-Est de la France depuis le milieu du 19e siècle. *Revue Forestière Française* XLVI-4: 335-341.

Becker M., Nieminen T.M. et Gérémia F., 1994 b. Short term variations and long term changes in oak productivity in northeastern France. The role of climate and atmospheric CO_2. *Annales des Sciences Forestières*, 51, 477-492.

Belingard C., 1996. Etude dendroécologique de la limite supérieure de la forêt dans les Alpes du sud en relation avec les facteurs climatiques et anthropiques. Thèse de doctorat, Université Aix-Marseille III, France 103 p.

Berger A., 1992. Le climat de la terre. Un passé pour quel avenir ? De Boeck Université, Bruxelles, 479 p.

Bert D., 1992. Silver fir (*Abies alba* Mill.) shows an increasing long-term trend in the Jura mountains. In Tree rings and environment (Ed. Bartholin t.S., Berglund B.E., Eckstein D. and Schweingruber F.H.), Ystad, Sweden, p. 27-29.

Daget P., 1977. Le bioclimat méditerranéen : caractères généraux, modes de caractérisation. *Vegetatio* 34: 1-20.

Diaz, H.F., Beniston, M. et Bradley, R.S., 1997. Climatic change at high elevation sites. Kluwer Academic Publishers, Dordrecht, 530 p.

Fritts, H.C., 1976. Tree ring and climate. Academic Press, New York, 567 p.

Gladzel, G., 1999. Historic forest use and its possible implication to recently accelerated tree growth in Central Europe. *In* "Proceedings of the International Seminar: Causes and consequences of accelerating tree growth in Europe", Nancy, 14-16 mai 1998, Karjalainen, T. Spieker, H. , Laroussinie, O. (Ed) 1999, p 65-74.

Guiot J., 1982. Response functions. *In*: "Climate from Tree-rings", M.K. Hughes, P.M. Kelly, J.R. Pilcher & V.C. Lamarche Jr. eds, Cambridge University Press, Cambridge. P 38-45.

Hoff C. et Rambal F., 2000. Les écosystèmes forestiers méditerranéens face aux menaces climatiques. In : Impacts potentiels des changements climatiques sur le fonctionnement d'un écosystème, en France au XXIe siècle, Mission inter-ministerielle de l'effet de serre et Ministère de l'aménagement du territoire et de l'environnement, Paris, p. 88-98.

Larcher, W., 1995. Physiological Plant Ecology. 3rd edition. Springer-Verlag, Berlin, 602 p.

Ledig, F., 1998. Genetic variations in *Pinus*. *In*: Richardson D.M. (Ed.), Ecology and biogeography of *Pinus*, Cambridge University Press, Cambridge, p 251-280.

Liang E., Vennetier M., Lin J., Shao X., 2003. Relationships between tree increment, climate and above-ground biomass of grass: a case study in the typical steppe, north China. *Acta Oecologica* 24 (2): p.87-94

Keeling C.D. and Worf T.P., 2001. Atmospheric CO2 records from site in the SIO air sampling network. In Trends: A compendium of data on global change, Carbon Dioxide Information Analysis Center, Oack Ridge National Laboratory, U.S. Department of Energy, Oack Ridge, U.S.A.

Keller T., Edouard J.L., Guibal F., Guiot J., Tessier L., 1997 a. Atmospheric CO_2 doubling impact on tree-growth in French Alps and French Mediterranean area. Atti del XXXIV Corso di Cultura in Ecologia, San Vito di Cadore, Sep. 1997, Università di Padova (C. Urbinati & M. Carrer eds.), 55-64.

Keller T., Tessier L., 1997 b. Climatic effect of atmospheric CO_2 doubling on radial tree-growth in southeastern France. *J. Biogeogr.*, 24: 857-864.

Kirsbaum M.U.F.and Fischlin A., 1996. Climate change impacts on forest. *In*: Climate Change 1995. Impacts, adaptations and mitigation of climate change : Scientific-technical analyses (Ed. Watson R.T., Zinyowera M.C., Moss R.H. and Dokken D.J.), Cambridge University Press, Cambridge, p. 95-130.

Lebourgeois D. et Becker M., 1996. Dendroécologie du pin laricio de Corse dans l'Ouest de la France. Evolution du potentiel de croissance au cours des dernières décennies. *Annales des Sciences Forestières*, 53 : 931-946.

Nouals D., Boisseau B., 1992. Cemagref Aix en Provence, Le pin laricio dans les Cévennes. Croisement raisonné de plusieurs outils d'évaluation du milieu. Cemagref Aix en Provence, 47 p.

Pauly H., Belrose V., 2005. La santé des forêts françaises: actualités de l´année 2004 - Sécheresse et canicule de l'été 2003 : observation en 2004 des conséquences sur les peuplements forestiers adultes. Rapport ; Ministère de L'Agriculture, de l'Alimentation, de la Pêche et de la Ruralité, Département Santé des Forêts ; Mai 2005, 11 p.

Picard J.F., 1995. Evolution de la croissance radiale du hêtre dans les Vosges. Premiers résultats sur le versant lorrain. *Annales des Sciences forestières* 52: 11-21.

Prentice I.C., 2001. The carbon cycle and atmospheric carbon dioxide. In . In Climate Change 2001: The scientific basis (Ed Houghton J.T., Ding Y., Griggs D.J., Noguer M., Van Der Linden P.J., Dai X., Maskell K. and Johnson C.A.), Cambridge University Press, Cambridge, p. 183-237.

Quézel, P, Médail, F., 2003. Ecologie et biogéographie des forêts du bassin méditerranéen., Elsevier, Paris, 2003, 571 p.

Ramaswamy V., 2001. Radiative forcing of climate change. *In:* Climate Change 2001: The scientific basis (Ed Houghton J.T., Ding Y., Griggs D.J., Noguer M., Van Der Linden P.J., Dai X., Maskell K. and Johnson C.A.), Cambridge University Press, Cambridge, p. 349-416.

Rathgeber C, Guiot J, Roche P, Tessier L., 1999. Augmentation de productivité du chêne pubescent en région méditerranéenne française. *Annals of Forest Science*, 56: 211-219.

Rathgeber C., Guiot J. et Edouard J.-L., 2000 a. Using a biochemical model in Dendroecology. Application to *Pinus cembra*. *Comptes Rendus de l'Académie des Sciences, série III,* 323, 5: 489-497.

Rathgeber, C., Nicault, A., Guiot, J., Keller, T., Guibal, F. et Roche, P., 2000 b. Simulated responses of *Pinus halepensis* forest productivity to climatic change and CO_2 increase using a statistical model. *Global Planetary Change*, 26: 405-421.

Rathgeber C., Nicault A, Guiot J., Kaplan J.O. et Roche P., 2004. Simulated responses of *Pinus halepensis* forest production to climate change and CO_2 increase using a biogeochemistry model. *Ecological Modelling* 166 (3) : 239-255.

Ripert C., Boisseau B, 1993. Ecologie et croissance du cèdre de l'Atlas en Provence. Cemagref Aix en Provence, 104 p.

Ripert, C. and Vennetier, M., 2002. Evaluations des potentialités forestières. Guide technique du forestier méditerranéen français. Chapitre 2 bis, Editions Cemagref Antony, 61 p.

Schweingruber F. H., Eckstein D., Serre-Bachet F., Bräker O. U., 1990. Indentification, presentation and interpretation of event years and pointer years in dendrochronology. Dendrochronologia, 8: 9-38

Spiecker, H., Mielikäinen, K., Köhl, M. et Skovsgaard, J., 1996. *Growth trends in European forests*. Springer-Verlag, Heidelberg, 372p.

Vennetier M., Hervé J.C., 1999. Short and long term evolution of *Pinus halepensi*s (Mill.) height growth in Provence (France) and its consequences for timber production. International Seminar "Causes and consequences of accelerating tree growth in Europe", Nancy, 14-16 mai 1998, EFI & ECOFOR (Org.).; Timo Karjaleinen, Heinrich Spiecker and Olivier Laroussinie (Editors), EFI Proceedings no 27, p. 263-265

Vila B., Nicault A., Vennetier M., 2001. Influence de la densité des peuplements sur la croissance en hauteur et radiale de *Pinus sylvestris* L. en région méditerranéenne française. *Forêt Méditerranéenne* tome XXII, N°1: 65-74.

Vila B., Vennetier M. 2003: Impact du changement climatique sur le déplacement d'une limite bioclimatique en région méditerranéenne, Cemagref Aix en Provence, IMEP, ECOFOR, octobre 2003, 141 p.

Vila B., Vennetier M., Liang E., Ripert C, Chandioux O., Guibal F., Submitted. Did global change already modify tree's productivity: Consequences on vegetation distribution in the French Mediterranean Ecosystem.