SILVER FIR DECLINE IN THE VOSGES MOUNTAINS (FRANCE) : ROLE OF CLIMATE AND SILVICULTURE

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ABSTRACT. Silver fir stands have shown severe defoliation in the Vosges mountains in the late 1970s and early 1980s. Based on the preliminary results of growth studies in other regions affected by decline in silver fir (i.e. Black-Forest), it was suggested that this decline could be the first sign of a breakdown of the ecosystem, following a long-term decrease in vitality. Various hypotheses regarding the role of air pollution were offered. A dendrochronological study, based on 200 plots, showed a sharp increase in productivity of the silver fir between 1850 and 1940, followed by a plateau. During the last 40 yr, severe climatic crises have occurred ; droughts were found to play a key role. Both long-term evolution and short term crises are well reproduced by a climatic model, based on monthly precipitation and temperature of the year of ring formation and of the previous 6 yr. The model explains 79% of the variance. An excessive stand density, responsible for the development of ill-formed crowns and for an increased competition for water, seems to play a major role in the dieback of some stands. Information available on the response of the stands to a potential deterioration of the soils, to possible changes of the climate, and to other modifications of the pollution climate does not allow a reliable prediction of the vitality of silver fir.

1. Introduction and Objectives

Silver fir (*Abies alba* Miller) dieback (the German "Tannensterben") has been the subject of great concern in the Federal Republic of Germany since the early 1970s. A significant deterioration of the crown condition of this species and of the Norway spruce (*Picea abies* (L.) Karsten) at the beginning of the 1980s has been documented on the observation plots installed in the late 1970s in the Baden-Württemberg region (South-West of Germany) (Schröter, 1983). The French DEFORPA (Dépérissement des Forêts attribué à la Pollution Atmosphérique) programme was started in 1984, following the observation of severely defoliated silver fir stands in the Vosges mountains, situated in the N.-E. of France (about 50 km from the Black-Forest). The Vosges Mountains are mainly covered with forests (about 0.4 x 10^6 ha). Silver fir is the main species. A ground survey has been conducted in this area since 1983, and in some other regions in France since 1985. This survey confirmed that the proportion of defoliated silver fir trees is significantly higher in the Vosges mountains than in the other regions where this species is present. In the Vosges mountains, defoliation increased slightly up to 1986 at high elevations (more than 750 m), whereas an improvement occurred at lower and medium elevations (less than 750 m) after 1983. However, the yellowing of the old needles, nearly non-existent in 1983, increased sharply in 1984 and 1985, and decreased in 1986 and 1987 (Landmann, 1988). The yellowing in the Norway spruce is the most prominent feature of the recent decline from the forester's point of view. In the silver fir, the symptom is hardly visible.

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Monitoring has been developed during the last 3 yr in order to obtain a comprehensive picture of the pollution in this forest area, remote from large point sources. Initial estimates of the total acid deposition suggest that the higher elevation forests receive a rate of about 2 kmole $H^{+}.ha^{-1}.yr^{-1}$, associated with total inputs of about 30 $kg.ha^{-1}.yr^{-1}$ S and 15 $kg.ha^{-1}.yr^{-1}$ N (Prévosto, 1988). These loads are much lower than those recorded in the heavily polluted areas in Central Europe. Possible spatial variations in the deposition rates within the study area are not known, and therefore the deposition rate could not be included as a variable in this study. SO_2, NO_x and O_3 are also recorded. As an average of the last 3 yr, the SO_2 level is low (10 to 15 $\mu.g.m^{-3}$ as an annual mean) with some significant daily peaks (up to 300 $\mu.g.m^{-3}$) during the winter, whereas the O_3 level is rather high (60 $\mu.g.m^{-3}$ as an annual mean) with very slight diurnal variations (Target, 1988).

Soils are generally acidic, poorly buffered and can therefore be considered as susceptible to acidification. The dominant soils are acid brown soils, proto podzols and podzols.

As a part of the DEFORPA programme, the studies recorded in this paper were developed primarily in order to describe the state of health of the Vosgian silver fir forests as objectively as possible.

Even if the data of the ground survey, focused on the crown condition, are considered to be reasonably accurate, a reliable assessment is not possible, because of the lack of knowledge about the long term baseline and the magnitude of possible fluctuations in the foliar biomass. In our opinion, this assessment had, on the one hand, to be associated with a precise definition of growth conditions, and, on the other hand, to take into account the time sequences of the recorded phenomena.

A study of silver fir growth during the previous decades was conducted to date and quantify a possible loss of vigor and then, on a statistical basis, to try to identify the probable causes, whether they are anthropogenic (pollution, silvicultural practices) or "natural" (climate, site conditions, pathogens...).

2. Materials and Methods

Thus, it is essentially a dendroecological study (Schweingruber, 1985 ; Villalba *et al.*, 1987) i.e. the close association of dendrochronology (based on the measurement of the annual ring width) and ecology (analysis of physical and biotic growth conditions). The study consists of two successive stages.

The first stage is devised to give a representative picture of the vitality of the Vosgian silver fir forests ; the sample of plots (n = 196) covers the whole range of silver fir in the region.

The choice of 196 plots was made so as to cover the diversity of all possible situations : i.e. geographical, geological, altitudinal, topographic and silvicultural situations. In contrast, the choice was intentionally neutral regarding the apparent state of health of the stands. A normal phytoecological inventory was carried out on each site : vegetation, soil and topographical observations.

Six firs, chosen from the dominant and co-dominant trees, were assessed with respect to needle loss and bored to the pith, at breast height (1.30 m), for the tree ring study.

The age of the studied trees is very varied (50 to 180 yr). The good cross dating of the individual series was made possible by the progressive underscoring of typical years, characterized systematically by a very poor (1870, 1880, 1892-93, 1907, 1912, 1915, 1922, 1929, 1934, 1948, 1956, 1976) or a very good (1916, 1961) growth.

Among the numerous factors likely to influence ring width, age has the primary role (Fritts, 1976). This precludes the direct comparison of trees and stands of varied ages and the identification of the influence of the other factors. The commonest way to circumvent this difficulty is to transform each measured ring width into a growth index (Mc Laughlin *et al.*, 1983) which is most frequently expressed in per cent, as the ratio of each actual width versus a reference value previously established for the corresponding current ring age (cambial age). The means of establishing these reference values varies a lot according to the authors. We have taken advantage of the abundance of the data to construct the general mean radial growth curve according to the current ring age. Without any smoothing, this curve appeared to be very regular (Figure 1). This is due mainly to the great age diversity : a variety of calendar years, and therefore various growth conditions (in particular meteorological ones) correspond to each cambial age. These opposing effects of growth tend to compensate each other.

Figure 1. Mean radial growth of silver fir versus cambial age.

This means of establishing the reference curve does not completely solve the problem of the interaction of the "age effect" and of a possible "date effect", but seems to be more suitable to minimize it than some of the methods commonly used in dendrochronology.

The second stage of the study relies on a less numerous sample chosen specifically with respect to foliar loss.

Eight pairs of plots were selected, each consisting of a healthy plot h and a severely damaged plot d. In most cases, the two plots were situated in the immediate geographic vicinity ; so, climate and pollution levels can be considered as identical.

At each plot, a phytoecological description and a complete dendrochronological study (on 6 trees) were carried out, using the same methods as in the previous general study. The soils were investigated in more detail, including a morphological description and chemical analyses of the horizons observed.

The parent material is generally the same in both plots of a given pair (Vosgian sandstone, intermediate sandstone, Permian conglomerate, granite, rhyolite, greywacke). Soils vary from acidic brown soils to podzolic soils. They are all very acidic. In the two plots of a given pair, the soils may be identical or different ; in the latter case, the more acidic and the less rich soil sometimes corresponds to the damaged stand, and sometimes to the healthy stand.

3. Results and Discussion

3.1. THE LONG TERM FLUCTUATIONS OF THE RADIAL GROWTH OF FIR

At first, it was important to test the hypothesis, often proposed at the beginning of the 1980s, that the increase of air pollution could have caused a decrease, starting at a date that should be identified, in the forest vitality, which has degenerated for a few years into dieback.

So, we produced the curve showing the evolution of the general mean of the growth indices for all the plots according to the calendar year (Figure 2-A ; continuous line). Its shape is very surprising, and reveals clearly some important trends : a very sharp increase in the radial growth potential between the mid 1800s and 1930-40 (about +70%), followed by a plateau or a slight decrease (-10%).

Although their authors did not notice this fact, a similar pattern can be observed in other studies : on the same fir in the Black-Forest (Gerecke, 1986), but also on *Tsuga mertensiana* in North America (Graumlich and Brubaker, 1986). Even if the definition of the productivity over time is somewhat variable between the different authors, several recent studies have demonstrated the more or less continuous increase of the primary productivity of some ecosystems during the last century in North-America (Hari *et al.*, 1986 ; LaMarche *et al.*, 1984 ; D'Arrigo *et al.*, 1987 ; Hornbeck, 1987 ; Jozsa and Powell, 1987) and during the recent decades in Europe, essentially for Norway spruce (Kenk, 1988).

3.2. THE CRISIS UNDERGONE BY THE VOSGIAN FIR FORESTS

The previous result does not rule out the possibility that the forest could have suffered from more or less serious and long crises. When observed carefully, the evolution of the mean growth index over the century shows several sharp growth decreases of variable duration and severity (Becker, 1987). The "current" crisis is very obvious and very severe, but, in fact, it started in 1973, reached its highest point in 1976, and, above all, one can observe a very clear recovery from 1981 onwards (Figure 2-A).

Moreover, this crisis was not the only one in this century. At least two others can be identified, nearly comparable in duration and intensity : 1916-25, centered around 1922, and 1943-51, centered around 1948. These crises may have been even more severe than they appear on the curve, because many of the most damaged trees during these periods have probably disappeared since. Fourchy (1951) described symptoms of dieback (foliar loss) in the Vosges which were very similar to those observed recently. A reliable comparison of the extent of this older decline with the current one is impossible because of lack of data. The German literature, well described by Cramer (1984), reports these two crises, as well as other, even earlier events. Furthermore, during the same periods, diebacks in oak also developed in various regions of France (Delatour, 1983 ; Becker and Lévy, 1983).

When looking at the evolution of the rainfall during the growing season in Strasbourg (Figure 2-B), it becomes evident that series of years with more or less serious deficits, like 1917-21, 1943-49 and 1969-76, play a decisive role in the initiation of these crises. Shorter series of years (1928-29, 1933-34) also had a strong influence on growth, but did not trigger off a generalized and prolonged crisis. We will return to the case of the dry period of 1959-64 later. Exceptionally cold winters (in particular 1956) may also have a strong influence on the growth during the following season, but, apparently, without a significant after effect.

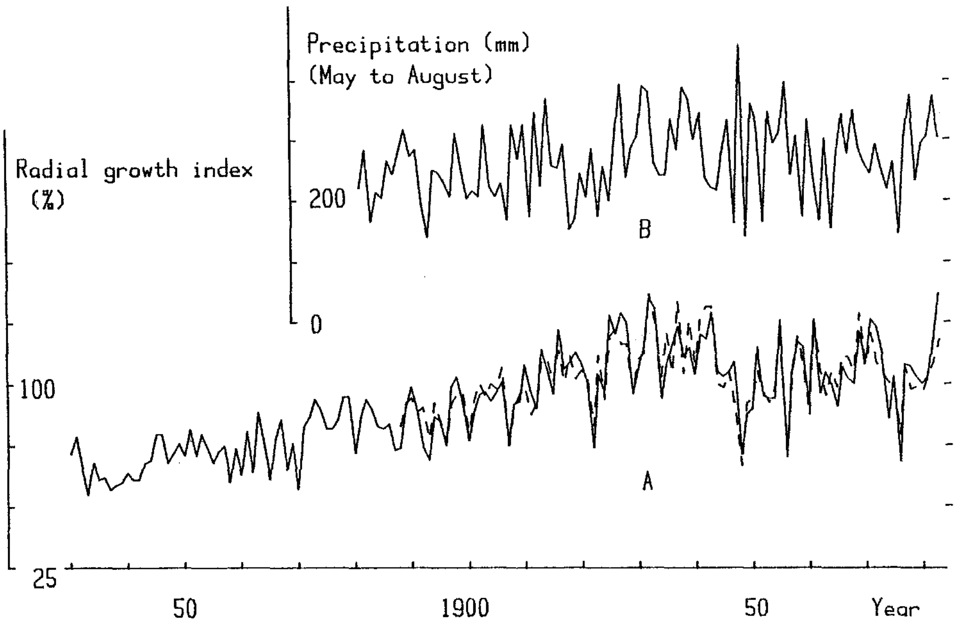

Figure 2. A. Actual radial growth indices (solid line), and indices estimated according to the climatic model (dotted line). B. Precipitations from May to August, inclusive, in Strasbourg.

3.3. CONSTRUCTION OF A CLIMATIC MODEL

As a further step of the study, we tried to quantify the role of some climatic parameters (rainfall, temperature) more accurately in the "explanation" of the radial growth of the fir. This was done with a stepwise multiple linear regression.

The meteorological data (monthly values) used are those from Strasbourg, since 1881. In absolute terms, these values are of course markedly different from these of the Vosges forest. However, there is little reason for their relative variations to be different. Conversely, these data have the advantage of being a long homogeneous series, which is fundamental for our purposes.

The thinking which leads to the best result will not be discussed in detail here (Becker, 1989, in press). It became obvious that, in addition to the usual meteorological data for the year n of the ring formation and for the summer of the previous year n-1, it is interesting to take into account the data for several years before ; in fact, up to year n-6, some monthly parameters take part significantly in the formation of the ring of the year n....

Among the monthly parameters used, one is particularly synthetic ; it is the hydric balance Bh, i.e. the difference between precipitation and potential evapotranspiration. ETP was calculated using Thornthwaite's formula ; this takes into account only the mean monthly temperature T. The climatic model constructed explains 79% of the total variance, which is very high in dendroclimatology, where explained rates rarely exceed 50%. This is very probably due to the reliability of the growth curve analyzed, itself resulting from a large database. The final model retains 18 significant parameters (at a probability 0.05 ; the direction of the correlation is given between brackets) :

year n :	T February (+), Bh May (+) and T June (-)
year n-1 :	T July (-), T August (-), Bh August (+) and Bh September (+)
year n-2 :	Bh April (+) and Bh August (+)
year n-3 :	Bh July (+), Bh August (+) and Bh October (+)
year n-4 :	Bh May (+) and Bh August (+)
year n-5 :	Bh April (+) and Bh August (+)
year n-6 :	Bh June (+) and Bh August (+)

Superimposed upon the observed growth curve (in continuous line), Figure 2-A gives the calculated curve corresponding to the model described above (broken line). One notices that the model reflects the actual variability very faithfully, whatever the "frequency" of the phenomena may be :

- the low frequency variability, that is, the long-term trends, at the century scale, as described above. These are a reality, and our results strongly support the idea of a mainly climatic determinism. It seems rather unlikely that this could be due to an artifact related to the standardization technique or a slow evolution of some silvicultural practices (a factor which has to be considered, especially in managed forests). Other hypotheses, including positive effect of a N "fertilization" by atmospheric deposition or an increased CO_2 level do not fit well with the time scale involved ;

- the medium frequency variability, that is, the crisis at the decade scale, such as the one we have just passed through, whose mainly climatic causes are established perfectly ;

- the high frequency variability, that is, the larger or smaller annual fluctuations ; all the characteristic years which have made the crossdating easier are well reconstructed.

The very high number of variables included in the model could throw some doubt on its statistical reliability (Verbyla, 1986). Therefore, the model has been validated according to a well-tried technique (Cook *et al.*, 1987). The calculations were repeated for a calibration period (1881-1960), used for the construction of a temporary model, and a verification period (1961-1983). The estimated values for the latter period are not significantly different from the observed ones, nor from the previously estimated ones. Thus, the relevance of the model is clearly established.

3.4. STUDY OF PAIRS OF PLOTS

The results given so far do not help us to understand why some stands obviously suffered much more than others during the last crisis, exhibiting sometimes heavy defoliation, or even dying in some cases.

Figure 3 illustrates the mean growth patterns of the healthy and the damaged plots. In fact, the growth index of damaged stands is very low, as expected, but this critical situation is the result of a long process, which sometimes began, and sometimes was amplified at the beginning of the 1960s. This is observed in all pairs, without exception. This behavior may be related to the rainfall deficits in the growing seasons of 1959, 1962 and 1964 (Figure 2-B). This "dry" period did not have a pronounced or prolonged effect on the mean growth (Figure 2-A), but it seems to have locally triggered off a real and permanent decline (Lévy and Becker, 1987).

However, climatic factors cannot explain the geographical distribution of the damaged stands, in particular in the studied pairs. A careful examination of the dendrochronological curves reveals some marked features in the evolution of the competition between the trees in the past. In particular, a sharp increase in the radial growth, if not consistent with the mean reference curve, probably reflects a decrease in the competition between the trees. The cause may be accidental (windfallen wood) or of a silvicultural nature (planned thinnings).

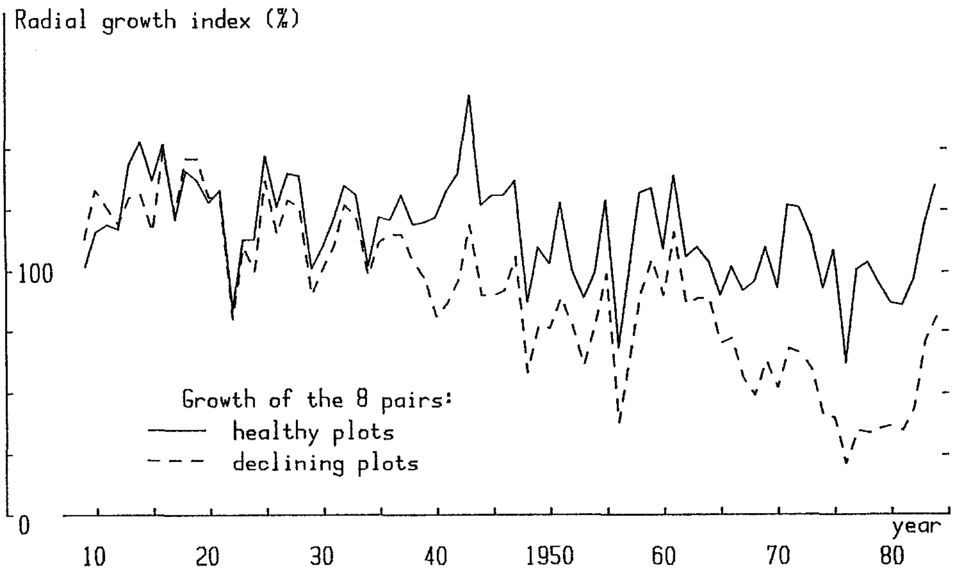

Figure 3. Mean curve of radial growth indices in the healthy and declining plots.

On this basis, we established that the number of "thinnings" was higher in the healthy plots than in the damaged plots during the 25 yr before the climatic stress of the years 1959-64. The only plot which did not follow this rule is located in a topographical position which favors a better hydric balance.

In order to confirm these hypotheses, we calculated some indices related to the competition within a stand. One of them is the height/diameter ratio (H/D) which integrates the whole life of the tree. With one exception, the ratio is higher for the d plots than for the h plots, sometimes very markedly. This indicates that the d plots were dense for a long time.

For the only pair which does not follow this "rule", the h plot is situated in a more favorable topographical position (a deeper soil at the foot of the slope).

A detailed inventory, not only of the living trees, but also of the stumps, classified according the estimated date of the cutting : 0 to -10 yr, -10 to -20 yr, -20 to -30 yr was then carried out in order to describe the competition during the last 25 yr. The approximate basal area of the plots was reconstructed since 1962. In order to be able to compare stands of different ages, the values were compared with the predicted values in stands of the same age and in the same site class, according to the yield tables of Badoux, 1966. The values obtained are presented in the Table I.

TABLE I - Evolution with time of the ratio : measured basal area/expected basal area (in %). (m : mean, s : standard error)

Calendar year	1962		1972		1982		1987	
	m	s	m	s	m	s	m	s
Healthy plots	114	34.9	107	26.6	97	20.2	83	14.8
Damaged plots	149	32.8	136	27.0	106	26.4	80	20.6

One can observe that 25 yr ago, during the climatic stress period which seemed to have initiated the decline, the basal area was higher than the "normal" one in the plots which are now declining.

The relative classification of the h and the d plots in 1962 is reversed for one pair only, but the hydric balance of the h plot was more favorable. For the other pairs where the differences are small, the relative over-density of the stands is even older, as established by the H/D ratio.

This change with time may perhaps explain some of the divergences between various European authors about the role of stand density on the decline : the open stands are to be seen here as a result, and not a cause of the decline as it is generally said. Whether that result can be extrapolated to other European regions concerned by the recent decline remains an open question.

4. Conclusions

Climate was found to have a major influence on the vigor and the health of the silver fir forests. The idea of more or less important lag effects, already mentioned by various authors (Sapanov, 1984 ; Tainter *et al.*, 1984 ; Becker and Lévy, 1983) is confirmed and quantified in this study. These lag effects seem to be largely responsible for the periodic regional crises, at a decade time scale. Our data also strongly support the idea that climate is the main cause of the general growth trends, at the century time scale, which have nearly passed unnoticed until now.

The relationship between the evolution of the foliar biomass and the evolution of the growth during the recent years is still somewhat obscure, but before concluding to some "abnormal" recent evolution in the relationship between these two parameters, one should consider the poor knowledge about foliar biomass "regulation" by trees and the poor reliability of some data commonly used in various speculations.

The combined effect of climate and silviculture is probably not exclusive. In particular, even if the results given here could not demonstrate such an effect specifically, one can not preclude the fact that some air pollutants may worsen the effect of some exceptional climatic events. On the other hand, the very low mineral content, due to the parent material, is characteristic of many Vosgian sites. The continuous exportation of forest products not compensated for by fertilization, an increased leaching of nutrients by acid deposition, and also the general increase in productivity for more than a century, illustrated in this study, may result in unprecedented nutritional disturbances because of the shifting of limiting factors. The possible threat related to the effects of a potential deterioration of the soils, partly as a result of acid deposition, of an increased O_3 level, of a changing of the "quality" of silvicultural management, is still very difficult to estimate.

Moreover, significant changes of the climate, which may have occurred and may occur in the future, as a result of an increased CO_2 level, would have considerable biological consequences on the forest ecosystem. Until now, the high frequency of severe crises during the last 40 yr was compatible with a high mean productivity. However, the threat of an increased frequency of severe climatic events should not be underestimated, especially for species very sensitive to climatic stress, like silver fir.

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