A FACTOR ANALYSIS OF CORRESPONDENCES APPLIED TO RING WIDTHS

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ABSTRACT

The factor analysis of correspondences has been applied to variations as a function of time of the ring widths of the Aleppo pine (Pinus halepensis Mill.) in the French Mediterranean region. This study, involving rings corresponding to 36 years of growth, demonstrates that a general climatic factor (factor 1) intervenes, as well as the constraint of external factors vis-à-vis individual reactions (factor 2).

Numerous factors govern ring width. The factor analysis of correspondences enables the demonstration that an important factor is the rain which falls during the vegetation period preceding the summer drought. The importance of the rainfall factor is conditioned by the date at which the average minimum daily temperature exceeds +4°C, as well as by the distribution of rain during the period in question and by the multiplying effect of the climate of the preceding year. The important effect of unusually low average minimum daily temperatures during the month of February is also stressed.

INTRODUCTION

The variations of ring widths of a given lignified species depend on intrinsic factors such as trunk form (Luck et al. 1970) or age (Ans 1973), as well as extrinsic climatic or ecological factors (Fritts 1962, 1965, 1966; Fritts et al. 1965 a, b; Serre et al. 1966; Borel and Serre 1969).
When investigating the relationships between ring width and directly measured or estimated external factors, stepwise multiple regression analyses are usually employed. The ring widths are the dependent variables (predictands, Fritts 1974) and the extrinsic factors are the independent variables (predictors, Fritts 1974). The already high performance of the stepwise multiple regression analysis has recently been improved by the introduction of the principal component analysis of the predictors such as precipitation and temperature (Fritts 1971, 1974; Fritts et al. 1971; LaMarche and Stockton 1974); the orthogonal property of the eigenvectors fully satisfies the assumption of non-correlation among the independent variables of the regression (Fritts 1974).

The present report deals with a factor analysis of correspondences (Benzecri et al.1973) applied only to ring width as a function of time, and also with the interpretation of the variations of the width which can be drawn from its results (Serre 1973). The method was subsequently used with the same material to study the role of intrinsic factors. It demonstrates perfectly the process of dependence between the width of successive rings (Ans 1976) already noted elsewhere (Serre 1973).

**MATERIALS AND METHODS**

The analysis was performed on the data gathered from the Aleppo pine (Pinus halepensis Mill.) growing in the region of Marseille, France. Twenty-four trees at the same site, in four age categories (60, 80, 100 and 140 years) were chosen. Three cores were taken from each tree, at 120° angles from each other (Serre 1973). The pines were carefully crossdated in order to detect any anomaly in ring chronology and the ring widths were measured to 0.01 mm under a microscope. Thirty-six rings per core were retained for study, corresponding to the years 1932 to 1967. The analysis was performed on 2,484 data (69 x 36) since only 69 of 72 cores were utilized.

The factor analysis of correspondences (Escofier-Cordier 1965; Benzecri et al. 1973) applies to the cases where, in a natural or experimental context, two sets (individuals : I and variables : J) or more are in relation whatever the nature of these sets may be. This sort of analysis can be considered as a particular case of the principal component analysis, but is distinguished from the latter by the use of the chi square statistic which supposes the utilization of the profile of the points rather than their actual values. Thus the “size” effect is attenuated in the comparison of individuals or of variables (Briane et al. 1974).

The chi square statistic gives such a symmetry to the clouds of points representing the sets I and J that at each factorial axis of the cloud of individuals (I) there corresponds a factorial axis of the cloud of variables (J) of the same eigenvalue. Thus it is possible to represent simultaneously individuals and variables on the plane defined by the axes which render maximum the moment of inertia of the clouds. The projection on the axes of the points representing I and J facilitates interpretation of these axes.

**DATA PROCESSING**

The analysis of correspondences was not performed directly on the 36 actual measured ring widths in view of several unsuccessful trials, but rather was effected on the annual frequency table of six width classes (Table 1).

In order to minimize the parasite influence arising from the individual factor and from age, the ring widths were first normalized. Each ring width of a core was divided
Table 1. Annual frequencies of ring-width classes during the 36 years studied.

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by the sum of the ring widths analysed on that core and the normalized ring widths as a whole were distributed among six classes of equal size. The normal ring widths of each core were then expressed by these classes. Finally, the annual frequency table of the 6 classes analysed (Table 1) was constructed: class 1 comprises the narrowest rings, class 6 the widest.

RESULTS

During the analysis, we retained only the first two axes (Table 2) which account for 62.11 and 26.59%, respectively, of the total inertia of the whole cluster of data points. We sought the significance of these axes by projecting on each of them the points of the two sets, width classes (I) and years (J) (Figure 1). The significance is based on the study of the relative proximity of the points of the two sets and also on the opposition of the extremes of each of the axes.

Significance of axis 1

The points of the "width classes" set are projected on the first axis in an orderly manner (Figure 1). Class 3 is near the origin, classes 1 (very thin) and 6 (very thick) are opposed in relation to class 3.
Figure 1. Projections of the points of the years and width-class sets on factor axes 1 and 2.
Table 2. Absolute contributions of the points of the width classes and years to the eigen value of the factor axes 1 and 2 retained for analysis.

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<th>Absolute contributions:</th>
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<td>Cl 6 278.709 114.679</td>
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| (J) 1953 43.313 5.127      | 1935 29.360 1.477        |
| 1955 3.463 45.028          | 1933 3.251 2.447         |
| 1956 204.129 96.311        | 1932 43.674 10.396       |
| 1957 139.507 44.348        | 1931 38.329 3.616        |
| 1958 38.329 .174           | 1930 38.325 3.616        |
| 1959 7.385 .038            | 1929 23.360 1.477        |
| 1961 11.848 10.374         | 1927 53.579 17.514       |
| 1962 .667 7.402            | 1926 38.325 3.616        |
| 1963 28.365 8.195          | 1925 49.805 10.825       |
| 1964 7.946 1.199           | 1924 39.722 15.561       |
| 1965 48.619 .821           | 1923 53.579 17.514       |
| 1966 2.242 22.635          | 1922 49.805 10.825       |

The points of the "years" set are apparently randomly distributed along the axis; 1936 and 1956 are on opposite sides of the origin. Knowing that these two years represent pronounced climatic particularities (Serre 1976a, Tables 3 and 4), the first factor can be interpreted as climatic.

In order to know in detail the climatic characteristics corresponding to the well opposed nature of width classes 1 and 6, an analysis was performed of the groups of years situated on the extreme left and the extreme right of the axis. Rainfall and temperature data for these years were obtained from the Observatory at Marseille, located 8 km from the pine site. They were considered separately or together for variable length periods (Tables 3 and 4), as a function of the results acquired during a prior analysis of the relationships between annual growth and the pattern of climatic records (Serre 1973, 1976a, b).

The analysis of these groups of years leads to the following findings:
1. The opposition of the two groups does not arise in an obvious manner from the total annual rainfall nor from the average annual temperature;
2. The annual rainfall-average annual temperature ratio (P/T), which constitutes an expression of average annual hygrometry, does not furnish any better explanation for their opposition;
3. Rainfall during the vegetation period preceding the summer drought (from about March to July for the species and region considered) is not totally satisfying either. It is certain, however, that this precipitation affects the distribution of the two groups of years but there are also one or several other associated factors.

The prior detailed analysis of the growth of the pine used in the present study (Serre 1973, 1976a, b) has shown that growth conditions during the years preceding
Table 3. Minimum average temperatures (°C) recorded by the Observatory at Marseille between 1932 and 1967.

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the formation of a given ring intervene in the formation of that ring and that their action is combined with that of rainfall during the vegetation period preceding the summer drought. The influence of the preceding year (and even of several others) on the width of a given ring is known and generally approached by considering either the meteorological data for that year and the width of the corresponding ring (Fritts 1962, 1971; Fritts et al. 1965b, 1971), or the type of liaison between the width of consecutive rings (Ans 1976). That rainfall has been considered and "the growth conditions during the previous year" have been introduced in the search for factors which could lead to a given width class by means of the ring width of that previous year.

The problem we faced was the means of expressing rainfall data of the current year and ring width of the previous year in comparable terms in order to determine the mode of combination of these factors. Each of these parameters was normalized. The average annual ring width was expressed on the basis of the average width of all the rings and the rainfall of the vegetation period preceding the summer drought of a given year was expressed on the basis of the corresponding average figure for the 36 years analyzed. These two values were combined by multiplication. The values obtained for each of the two extreme groups of years on the first axis give the most faithful image of the distribution of the years on the axis considering their contribution to the eigen value of the axis (Table 2). The years located to the left of the origin present the lowest values of the product, those situated to the right the highest values.

The existence of three exceptions for the data located to the left of the origin (1953, 1956, 1965) led us to more closely examine the meteorological characteristics of each of these years (Tables 3 and 4). The following could be further defined:

1. The very low minimum temperatures of February are implicated in the formation of very narrow rings or even in their nonformation. Although 1956 was normal from the point of view of rainfall, it was exceptionally cold in February: the minimum monthly average temperature at Marseille was -4°C, as opposed to +3.5°C for the years 1922-1971 (Serre 1976a). In addition, such temperatures can plainly be located anatomically because they lead to the formation of frost cells (Monange 1961; Parker 1963; Serre et al. 1966; Glerum and Farrar 1966).

2. The useful quantities of rain during the vegetation period preceding the summer drought depend on the minimum February temperatures. In the Aleppo pine, cambial reactivation occurs about one month following the establishment of average daily minimum temperatures greater than +4°C (Serre 1976a). When February temperatures are lower than this required threshold, rainfall during March does not appear to count among the useful quantity of precipitation.

3. Considering the growth conditions of the previous year, the relationship between the useful rainfall during the vegetation period preceding the summer drought and the width of a given (especially a narrow) ring depends on the relative importance of rainfall at the beginning and the end of this period. The relationship is direct when there is more rainfall at the beginning than at the end of this period but can be aberrant when the reverse is true (1953, 1965). This finding is consistent with the distinction, made during the analysis of the annual growth pattern of the Aleppo pine (Serre 1976a), between rain falling at the beginning of the vegetation period preceding the summer drought (March, April, beginning of May) which is related to the value of maximal acceleration of cambial activity, and rain falling at the end of this period (end of May, June and July) which prolongs the variable part of the phase of high cambial activity (Serre 1976a, b).
We also considered the product of the expressions of the previous growth conditions and of the annual rainfall, or of the ratio $P/T$, where $P$ is the annual rainfall and $T$ is the average annual temperature; these products gave no better approach to the distribution of points along the axis than that just discussed. When January and February rainfalls were added to that occurring during the vegetation period preceding the summer drought, the proposed interpretation was not improved either.

Factor 1, which integrates both the climatic conditions (rainfall and temperature) of the year preceding the formation of the ring and those of a part (March to July) of the year of its formation, is a "general interest" factor (Benzecri et al. 1973), as expected from the type of analysis utilized.

Significance of axis 2

Contrary to what is seen on axis 1, the two extreme classes 1 and 6 of the width classes set are close together on one side of the axis and oppose classes 2 and 3 (Figure 1).

The distribution of the points of the years set around classes 1 and 6 is an exact reproduction of that which was observed on axis 1 for class 6 but only partially so for class 1.

The years 1956, 1957, 1936, 1945 and 1938 on one hand, and 1955, 1949, 1954, 1966 and 1960 on the other hand, present, among the points of the set "years", the highest absolute contribution to the eigen value of the axis (Figure 1, Table 2). The opposition of these two groups of years is expressed in the following observations:

1. According to Table 1, the distribution of width classes frequencies is highly asymmetrical for the left-hand group of years and is symmetrical for the right-hand group.

2. At the two extremes of the axis, 1956 opposes 1955. The dominant climatic element of 1956 was the exceptional cold of February (Table 3); all the rings from this year are very narrow and are distributed almost exclusively in one class. In opposition is 1955 where the growth conditions of the previous year (evaluated as we have just explained) and rainfall of the vegetation period preceding the summer drought were average (Table 4); all the rings from this year are of varying width and are distributed among all the classes. The years which, by their absolute contribution to the eigenvalue of the axis, are close to those at both extremes of the axis exhibit, as them, dominant characteristics (left-hand group) or average characteristics (right-hand group) concerning the factors discussed for axis 1.

Axis 2, therefore, translates the external factor-provoked constraint on the tree: in the presence of a strong constraint (favorable or unfavorable) the response of all the individuals is uniform, resulting in the observed uniformity of classes; when the constraint is weak, the response of each tree becomes a function of its own nature, resulting in the variety of classes observed.

The class 4 ring widths are the closest to the average width of all the rings examined (Serre 1973); it is interesting to note that the minimum intervention of factor 2 is translated as classes inferior to the average (Figure 1).

CONCLUSIONS

The factor analysis of correspondences applied to the study of tree-ring width variations as a function of time emphasizes the role of climatic factors.
Because of the significance of the initial two factor axes, which extract 88% of the total inertia of the points considered, we could demonstrate the multiplying action of the growth conditions during the year preceding the formation of a ring towards the rainfall of the vegetation period preceding the summer drought. In addition, we could demonstrate the effects of climatic constraint and thereby the conditions of maximum manifestation of individual idiosyncrasy.

Such results show that the factor analysis or correspondences can be used for any analysis of ring width, either alone or as a preliminary study to more extensive research concerning the causes of these variations.

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