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ASSESSMENT OF SIMILARITIES OF DENDROCHRONOLOGICAL SERIES

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The existing methods for determining similarities among dendrochronological series are considered. A new method is proposed, based on using the mean value of cosines of angles formed by vectors which express changes in the width indices of annual rings for continuous years.

In dating annual tree rings, in selecting models for dendroclimatological analysis, in correlating tree-ring series, and in establishing the relationships between external environmental factors and tree growth, one frequently finds it necessary to have some information on the similarity (correlation) between the time series being compared.

Relative and absolute dating is done most of the time visually, by comparing ring patterns either directly on tree sections or on graphs ("skeletal," ordinary, or semilogarithmic) (Douglass, 1919; Glock, 1937; Kolchin, 1962). This method is based on the recognition of characteristic (chiefly the narrowest) rings and on determination of succession of alternating narrow and wide rings. It is widely used because of its simplicity and low labor consumption, but all it offers is a qualitative correlation of time series. The visual method is most promising when the effect of a limiting factor is manifested.

It is difficult and often impossible to date samples by characteristic rings in regions favoring tree growth. In this connection, methods based on taking into account the character of variability in size of all the annual rings are used to determine the degree of similarity of curves. In comparing time series count is made of the number of deviations of the same and opposite sign for growth increment during continuous years (Hansen, 1941).

Huber (1943) has worked out a special method for synchronizing curves by taking into account the number of divergences (variance). In order to estimate the synchronism of curves he proposed to compute the asynchronism coefficient (Gegenlaufigkeitswert), which gives the percentage of segments of a curve running in the opposite direction within the interval being compared. The reciprocal value, synchronism coefficient or Gleichlaufigkeitswert, is being used more frequently at present (Rudakov, 1952; Bitvinskas, 1965; Liese, 1970). A shortcoming of the synchronization method is that it ignores the range of fluctuations in increment values.

More complex and time-consuming methods involving digital computers have been coming into use for curve correlation and tree-ring dating. For example, in the dating of short series of tree-growth increments the correlation coefficient was computed for each possible combination of samples of known and unknown age (Howland, Sharrock, and Raskin, 1964).

In testing correlation between tree-growth increment and environmental factors, the correlation coefficient is widely used (Glock, 1941, 1955; Schulman, 1945, 1951; Dobbs, 1951; Fritts, 1963). It does not, however, always reflect the actual correlation between time series; specifically, it makes no allowance for the degree of synchronism between the series being compared. Low correlation-coefficient

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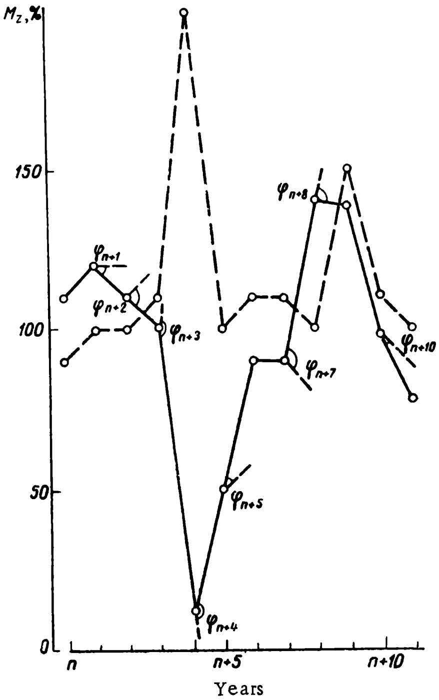

Fig. 1. Graphs of changes in ring-width indices for two series A (---) and B (———) and the angles formed by them.

values may be obtained with a high degree of synchronism if long-term tendencies in increment changes are opposite in sign (Rudakov, 1952, 1971).

Though the similarity coefficient proposed by Komin (1970), which is synchronism coefficient multiplied by correlation coefficient, is a better measure of the degree of similarity between time series, it has the same shortcomings as have the initial coefficients.

For the purpose of establishing the closeness of correlation between long time series, Glock (1942) proposed to compute a coefficient of tendency t, which takes into account the magnitude of synchronous changes:

$$t = \frac{\sum AB}{\sum |A| \cdot |B|},$$

where A is the difference in growth increment (climatic factor) between contiguous years in one series; B is the same in another series. If t = 0, there is no correlation between the curves; if t = +1.0, the curve segments coincide in direction; if t = —1.0, the segments are opposite in direction. A disadvantage of t is that increments equal in sign but differing in magnitude may yield a much larger product than can small, but equal, increments. Also, this method does not take into consideration those cases where increments are equal to zero in one or both series.

American workers also make wide use of indices of increment series, such as sensitivity coefficient, standard deviation, distribution patterns of index values, etc. (Fritts, 1968). Although these indices do not directly reflect the degree of similarity between curves, they are nevertheless quite useful in selecting cross-dated models in the same region.

At present, the search continues for more reliable methods, which would make it possible to form judgement as to the real similarity between long time series. We propose to use for this purpose the mean value of the cosines of the angles formed by vectors each of which corresponds to change in the index of growth-ring width for two consecutive years. The coefficient of similarity is computed from the following formula:

$$S = \frac{1}{N-1} \sum_{n=1}^{N-1} \cos \varphi_n, \qquad (1)$$

where N is the length of the series being compared.

Theoretically, the values of S may vary from —1 to +1. The value of S will be +1 for series which coincide in the sign and magnitude of indices. If the value of S is negative and close to —1, the indices of the curves being compared are opposite in sign. In determining the S value one has to take into account the ratio of scales adopted for time and the values of increment indices. As applied to dendrochronological series, it is desirable to use the distance between two contiguous years as the unity scale.

Figure 1 gives an example of how to construct angles between the vectors representing changes in the indices of growth-ring width for two series (A and B), for which similarity coefficients have been computed. For the convenience of graphic representation the scale of distance between two contiguous years is taken as equal to 10. The vectors showing changes in ring-width indices between two contiguous years form definite angles ranging from φ_n to φ_{n+10}. These angles and their cosines have the following values:

$\varphi_n = 0°$; $\cos 0° = 1.00$

$\varphi_{n+1} = 45°$; $\cos 45° = 0.71$

TABLE 1

Type of conditions in the habitat	Larch		Spruce	
	no. of series	no. of models	no. of series	no. of models
Abundant moisture, running water	1	29	4	21
Moist	2	22	5	15
Dry	3	22	6	22
Dry	3a	11	—	—
Dry	3b	11	—	—

$$\varphi_{n+2} = 90°; \quad \cos 90° = 0.00$$
$$\varphi_{n+3} = 168°; \quad \cos 168° = -0.98$$
$$\varphi_{n+4} = 161°; \quad \cos 161° = -0.95$$
$$\varphi_{n+5} = 50°; \quad \cos 50° = 0.64$$
$$\varphi_{n+6} = 0°; \quad \cos 0° = 1.00$$
$$\varphi_{n+7} = 123°; \quad \cos 123° = -0.54$$
$$\varphi_{n+8} = 90°; \quad \cos 90° = 0.00$$
$$\varphi_{n+9} = 0\ ; \quad \cos 0° = 1.00$$
$$\varphi_{n+10} = 22\ ; \quad \cos 22° = 0.93$$
$$\sum_{n}^{n+10} \cos \varphi_n = 2.81$$

In order to obtain a mean value of the similarity coefficient for the series shown in Fig. 1, the algebraic sum of cosine values (2.81) must be divided by the total number of angles (11). The similarity coefficient for these series turns out to be 0.26.

To set up a program for the computation of the similarity coefficient by a Promin'-2 digital computer, Eq. (1) was transformed in the following manner. The scalar product of two vectors is known to be the product of the lengths (modules) of these vectors and the cosine of the angle between them

$$\bar{A}\,\bar{B} = AB \cos \varphi. \tag{2}$$

From (2) it follows that

$$\cos \varphi = \frac{\bar{A}\,\bar{B}}{AB}. \tag{3}$$

Taking the values of $\bar{A} = (C,\ A_{n+1} - A_n)$ and $\bar{B} = (C,\ B_{n+1} - B_n)$, while $A = \sqrt{C^2 + (A_{n+1} - A_n)^2}$ and $B = \sqrt{C^2 + (B_{n+1} - B_n)^2}$ and substituting them in (3) we obtain

$$\cos \varphi = \frac{C^2 + (A_{n+1} - A_n)(B_{n+1} - B_n)}{\sqrt{C^2 + (A_{n+1} - A_n)^2}\sqrt{C^2 + (B_{n+1} - B_n)^2}}, \tag{4}$$

where C is the scale of distance between contiguous years in relation to ring-width indices.

The formula for the computation of the similarity coefficient in an unfolded form is

$$S = \frac{1}{N-1} \sum_{n=1}^{N-1} \frac{C^2 + (A_{n+1} - A_n)(B_{n+1} - B_n)}{\sqrt{C^2 + (A_{n+1} - A_n)^2}\sqrt{C^2 + (B_{n+1} - B_n)^2}}. \tag{5}$$

The computer program is based on Eq. (5) and it allows us to compute the similarity coefficient for series of any length; the algebraic sum of cosines is build up by instalments, 70 values in each.

In order to test the proposed method of similarity determination, we took six series of growth-increment indices obtained for larch and spruce in the lower reaches of the Taz River. The series are characterized briefly in Table 1. The similarity coefficients computed for the series are given in Table 2. The scale of distance between contiguous years was taken as unity.

TABLE 2

No. of series	1	2	3	4	5
2	0,765	—	—	—	—
3	0,747	0,777	—	—	—
4	0,392	0,551	0,515	—	—
5	0,394	0,372	0,450	0,636	—
6	0,414	0,385	0,569	0,665	0,718

The data of Table 2 indicate the presence of a high degree of similarity between the series of the same tree species, the similarity coefficient being higher for larch than for spruce. In order to estimate the degree of similarity within a uniform group of model trees, series No. 3 was divided in two equal parts (11 models in each). As was to be expected, comparison of series 3a and 3b (see Table 1) yielded a maximal value of the similarity coefficient (0.814).

The proposed method of determining similarity between time series can be used in dendrochronological and dendroclimatological studies of various kind. With the aid of the similarity coefficient one can carry out relative and absolute dating of rings in wood of unknown age, select model trees that had been responding in a similar way to environmental changes, and exclude models manifesting strong individual variations in the character of growth; one can also determine the degree of similarity between growth-ring series established for a single region and for regions separated by certain distances. Also, this method permits establishing the closeness of correlation between environmental factors and the indices of annual increments in woody plants.

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