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PERIODIC VARIATION IN THE GROWTH INDICES OF SIBERIAN LARCH IN THE TAZOVSKAYA FOREST TUNDRA AND ITS FORECASTING

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In a previous study (Berri et al., 1976), we have separated the determinate (trend, periodic functions) and random components in an 867-year dendrochronological series, mainly reflecting the thermic conditions of the summer period. Summation of the 12 most representative harmonics and the trends gave a good approximation to the observed series, smoothed by the use of 11-year sliding means. This has allowed us to forecast the variation in growth indices of Siberian larch until 2200, with the possible effect of anthropogenic factors left out of account.

Analysis of periodic variation in time series is often limited by the fact that they are too short. One of the present authors has recently obtained a dendrochronological series for Siberian larch (*Larix sibirica*) by the lower Taz River (Western Siberia), covering 867 years (1103 to 1968). The series contains both short and long (secular and super-secular) cycles, in so far as only old (235-537) model trees were used for its construction, and growth indices were calculated by the corridor method (Shiyatov, 1975).

The methods previously described by Berri et al. (1976) were used on the dendrochronological series to separate determinate (trend, periodic functions) and random components. The determinate part of the series could be represented by a complex periodic function with a linear trend:

$$Y_{(t)} = a + bt + \sum_{j=1}^{n} A_j \cos\left(\frac{2\pi t}{T_j} - \varphi_j\right), \tag{1}$$

where $a + bt$ = linear part of the equation; A_j, T_j, φ_j = amplitude, period, and phase of the j-th cosine curve.

The distinction between this method and others for the separation of hidden periodicity lies in the algorithm used to find the amplitude and periods of the component harmonic expressions (1). In methods of spectral analysis, the usual final aim is to find the best approximation of the original series as a sum of sine or cosine curves, whose periods change according to definite rules. The component random series are approximated just as well as the determinate part, so that the separated periodicity does not always correspond with the real periodicity of the process. In the development of our method, the accuracy of approximation of the time series is not the main criterion, since real processes can contain different proportions of regularity and randomness.

It is assumed that the oscillations in time have a certain scatter for amplitude and period around particular mean values A_j and T_j. The search for the mean values is carried out by approximation of a series of single harmonics, which are multiples of the pitch of the time series. The criterion for selecting the values of A_j and T_j is the least mean square deviation of a given cosine curve from the mass of data by comparison with other cosine curves with a similar period, i.e., a period is selected from a set of similar periods to correspond as closely as possible to the studied series. This gives several real harmonics which are most representative of the whole duration of the time series, which can then be used to approximate and forecast the values of the series. The error of such an approximation in fact reflects the action of random factors which cannot be represented in the deter-

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TABLE 1. Most Representative Harmonics in the Oscillations of Growth of Siberian Larch

T_j, years	φ_j, radians	A_j, %	$\frac{S}{T_j} - 0.5$	Amplitude relative to mean value for series A_j/a	Amplitude relative to approximation error of series A_j/ε	P_j
12	1,74	4,16	71,9	0,04	0,147	0,422
20	2,20	5,40	43,0	0,05	0,191	0,410
37	1,96	6,70	22,9	0,07	0,238	0,382
110	1,06	11,1	7,4	0,11	0,394	0,320
62	2,36	8,00	13,5	0,08	0,284	0,306
24	1,35	4,80	35,7	0,05	0,170	0,303
41	2,24	6,50	20,6	0,06	0,230	0,285
92	5,65	8,60	9,0	0,09	0,305	0,245
76	3,91	7,20	10,9	0,07	0,255	0,195
170	1,42	10,4	4,6	0,10	0,370	0,171
50	2,18	4,20	16,9	0,04	0,150	0,101
350	2,46	7,50	2,0	0,08	0,266	0,042

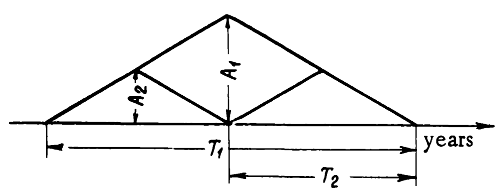

Fig. 1. Interaction between amplitude and period of sawlike oscillations (A, T are the amplitude and period of oscillation, $T_1 = 2T_2$, $A_1 = 2A_2$).

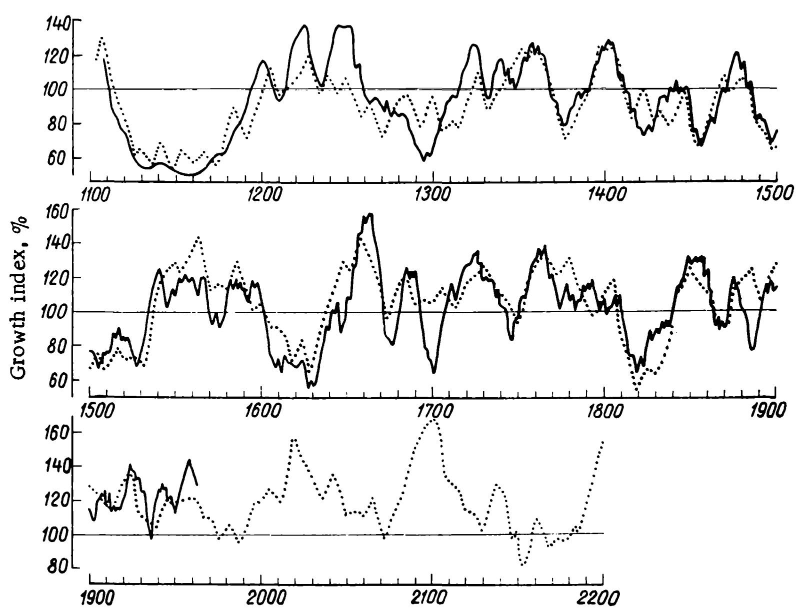

Fig. 2. Oscillations in the growth indices of Siberian larch, smoothed by taking 11-year sliding means (_____), and the values of the approximation function $Y_{(t)}$ for the 12 most representative harmonics and the linear trend (.....).

minate part of the series. The value of the error provides further information on the structure of the series.

The origin of the coordinates was taken as the middle of the series, i.e., the year 1536. The distance in years from the origin along the time axis to the periodic maximum T_j is given by the formula

$$\Delta T_j = \frac{\varphi_j}{2\pi} T_j. \quad (2)$$

The coefficients of the function are determined in two stages: a linear portion is first separated (a = 99.5; b = 0.0015 for the given series), and the rest of the series is then approximated by independent different periods, all multiples of the single-year unit, up to the value coinciding with the length of the series.

The representativeness of a period was estimated by a complex dimensionless parameter P_j, including the number of observed periods $S/T_j - 0.5$ (S is the duration of series, T_j is the duration of period; the observation of a period is considered possible if $S > 0.5T_j$), the relative amplitude A_j/a (A_j is the amplitude of the period, a is the mean value of the growth indices in the series), and the significance of the amplitude A_j/ε (ε = 28.2 is the mean square error of approximation of the series):

$$P_j = \left(\frac{S}{T_j} - 0{,}5\right) \frac{A_j}{a} \cdot \frac{A_j}{\varepsilon}. \quad (3)$$

Formula (3) allows one to compare the significance of harmonics of different amplitude and period separated from series of different length. Long periods may coincide with the length of the series; although they are often representative in amplitude, they must inevitably be nonrepresentative owing to lack of replication. This also means that the length of such periods cannot always be accurately determined.

The simple geometric principle of sawlike oscillation (Fig. 1) was used to combine representativeness, amplitude and number of replications of the period. It follows that one period of double amplitude can be broken down into two periods of single amplitude. Therefore, the representativeness of harmonics for amplitude and number of replications emerge as cofactors in determining the general representativeness of a period. The amplitudes are normalized in terms of the values for mean growth index a and approximation error ε.

The representativeness of all periods tends to infinity as the approximation error tends to zero. The representativeness of harmonics increases with increasing amplitude and length of the series studied and falls as these decrease.

Table 1 shows the characteristics of the 12 most representative harmonics in the dendrochronological series, obtained by formula (1). The length of most of these coincides with or is close to the length of cycles shown by various authors for natural processes. The absence of short-period components is linked with the fact that the program at present only allows the approximation of 12 harmonics at a time. Short-period oscillations have low amplitude and are unlikely to be separated. The cycles which were most representative in amplitude were selected for forecasting and approximation, since these are mainly responsible for the background values of tree growth.

In the actual series for Siberian larch, the effect of random factors accounts for 28.2% of the growth index values — this being the least mean square error of approximation of the series of annual figures. The total effect of random factors is almost three times greater than the maximum amplitude of any of the harmonics separated. In relation to the value for the mean index of the series, the effect of random factors is given by the same figure of 28.2%, since the mean value is close to 100 (99.5), i.e., in this case the mean square deviation coincides with the value for deviations from the mean growth index. Most of the effect of random components is due to short-period oscillations 2-4 years in length.

Smoothing the observed dendrochronological series by taking 11-year sliding means almost halved the mean square error of approximation (12.9%). As can be seen from Fig. 2, there was good coincidence between the smoothed series and the series obtained by summing the 12 most representative harmonics in Table 1 and the linear trend. This gives us the possibility of forecasting long-term oscillations in the growth of Siberian larch and thus the thermal conditions during the summer in the given region. It must be noted, however, that this forecast cannot take any account of changes in climate caused by human activity.

Since the series of growth indices for Siberian larch in the given region mainly reflects the thermal conditions during summer (Polozova and Shiyatov, 1975), a cooling of the climate in the north of Western Siberia can be expected at the end of the 20th century and beginning of the 21st, and again in the middle of the 21st, and for almost all the 22nd. The climate can be expected to be warmer in the first half of the 21st century, at the transition from the 21st to the 22nd, and at the end of the 22nd (Fig. 2). It is essential to take into account that fact that the linear part of the equation (a + bt) may itself be the rising phase of a very long period, whose characteristics could not be found from the series studied. The forecast values for growth indices over the period 1969-2200 may thus be slightly overestimated.

The forecast obtained essentially coincides with the results of other workers. Thus, according to Sazonov (Druzhinin et al., 1974), a fall in solar activity can be expected during the following periods: 1980-1990, 2070-2080, 2160-2190. Our series also forecasts a marked reduction in the growth of Siberian larch during the same periods (Fig. 2). According to Maksimov (1970), change in solar activity is leading to an increase in the ice load of the northern seas, reaching the level of the end of the last century in 1982-1992. The reasonable coincidence of these long-term forecasts increases their reliability, especially since they were obtained by different authors using quite different data.

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