Collaborative Paper

REGIONAL RESOURCE MANAGEMENT

VOLUME I

L. Kairiukstis
Editor

Papers presented at the Workshop on
REGIONAL RESOURCE MANAGEMENT
September 30-4 October, 1985
Albena, Bulgaria

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International Institute for Applied Systems Analysis
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3.1.2 NATURAL FLUCTUATIONS OF CLIMATE IN THE EASTERN REGIONS OF THE USSR BASED ON TREE-RING SERIES

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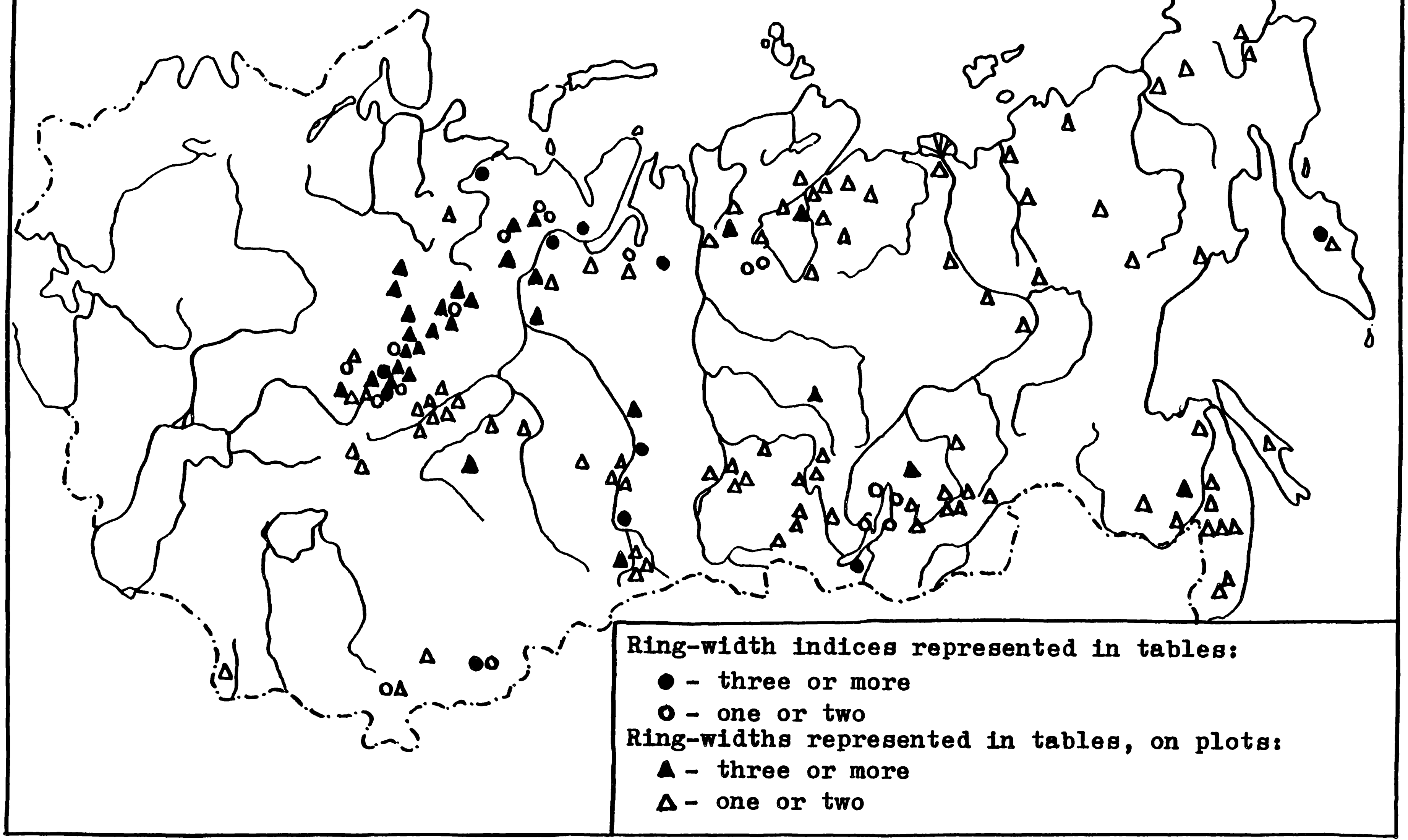
Tree-ring chronologies

Spacious territories of the USSR (the Urals, Siberia, Far East, Middle Asia) are comparatively poorly studied from the dendrochronological point of view. More or less systematic investigations began from 1960's. Tree-ring analysis was mainly used for reconstructing climatic and hydrological conditions, for studying forest ecosystems dynamics, environmental and tree-ring cycles, for dating catastrophic phenomena.

In most cases living coniferous trees were used in constructing tree-ring series. Archaeological and subfossil wood were used rarely. At present about 350 tree-ring chronologies are available from the eastern regions of the USSR, as well as tables of ring-width and its indices and plots. Fig.1 shows distribution of the tree-ring chronologies obtained for the eastern regions of the USSR. The most investigated areas are the Urals, Southern and Northern Siberia, the least investigated ones are Central Sibiria, Far East and Middle Asia. The most

Fig.1. The distribution of the obtained tree-ring chronologies in the eastern regions of the USSR



abundant are chronologies of Pinus sylvestris L. (about 150), Picea obovata Ledeb. and P. schrenkiana Fisch et Mey (about 90), of some species of Larix genus (about 80), Pinus sibirica Du Tour and P. koraiensis Sieb. et Zucc. (about 35). However, only 72 series have been recently published as tables of ring-width indices. The most long-term are the chronologies of Juniperus turkestanica Kom. (1224 years, Middle Asia, K.D.Mukhamedshin,1978; 808 years, Middle Asia, N.V.Lovelius, 1979) and of Larix sibirica Ledeb. (1010 years, the Polar Urals, S.G.Shiyatov,1981; 867 years, West-Siberian forest-tundra, S.G.Shiyatov,1975; 677 years, Altai, M.F.Adamenko, 1978). At present 12 chronologies over 500 years are available.

Sparsely distributed chronologies do not allow for analysis as tree-ring variability and climate over the whole territory. Therefore we have restricted ourselves to the series of coniferous species growing in high mountains and subarctic regions, containing the most reliable climatic information in ring-width indices.

Materials and methods

Analysis of tree-ring variability in the eastern regions of the USSR has shown that Larix genus are best suited for dendroclimatic reconstructions. Ring-width indices of Larix contain more reliable climatic information than those of Pinus, Picea and Abies. This may be caused by biological and ecological peculiarities of the larch, such as light-loving, poorer canopy density, deciduous, ability for better usage of thermal conditions of the vegetation season in biomass

Table 1

Characteristic of dendrochronological series used in this paper

NN series	Regions	Altitude	Species	Number of trees	Length of series	Mean sensitivity	Authors
1	2	3	4	5	6	7	8
1	Polar Urals, Rai-Iz massif	150-300	Larix sibirica	10	1648-1964	0.36	Shiyatov, in the press
2	- " -	150-380	- " -	71	960-1969	-	- " -
3	Subpolar Urals, Neroika Mt.	550-700	- " -	14	1673-1970	0.43	- " -
4	- " -	- " -	- " -	52	1673-1970	0.38	- " -
5	Northern Urals, Konzakowski Kamen Mt.	800-950	- " -	23	1598-1969	0.29	- " -
6	- " -	- " -	- " -	70	1590-1969	0.33	- " -
7	Southern Urals, Iremel massif	1000-1100	- " -	11	1770-1972	0.31	Shiyatov, 1978
8	Jamal peninsula, Chadyta-Jaha river	15-30	- " -	14	1656-1982	0.39	Shiyatov, not published
9	West-Sibirian forest-tundra, Lower Taz river	- " -	- " -	22	1624-1969	0.34	Shiyatov, 1984a
10	- " -	- " -	Pinus sibirica	27	1273-1969	0.18	Shiyatov, 1973
11	- " -	- " -	Picea obovata	136	1245-1969	0.24	Shiyatov, 1972
12	- " -	- " -	Larix sibirica	156	1103-1969	0.25	Shiyatov, 1977
13	- " -	- " -	- " -	30	1103-1969	0.27	Shiyatov, 1975

1	2	3	4	5	6	7	8
14	Eastern Taimyr, Lower Khatanga river	10-15	Larix gmelini	20	1514-1977	0.51	Shiyatov,1979
15	Putorana Plataeu, Tembengi Lake	Upper timberline	- " -	15	1866-1969	0.28	Galaziy,1981
16	Khamar-Daban mountain range, Langatui river	1710	Pinus sibirica	20	1858-1959	0.10	Galaziy,1981
17	Zailiyskiy Alatau, Talgar river	2800	Picea schrenkiana	20	1782-1978	0.14	Boršceva,1981a
18	Kungey Alatau, Satty site	2100-2400	- " -	16	1590-1978	0.15	Boršceva,1981b
19	Kamchatka, Tolbachik volcano	1300-1400	Larix kurilensis	11	1793-1980	0.23	Balčiunas and Krikšciuniene, 1984

increment. Therefore in our report the tree-ring series of Larix sibirica Ledeb., L. gmelini Pilger and L. kurilensis Mayr growing at the upper and polar boundaries of forest vegetation were basically used. Brief characteristics of these series are given in Table 1.

Along the two profiles - the Urals (meridional) and the Subarctic (latitudinal) ones the majority of standardized chronologies were obtained. The Urals high mountain profile is 1300 km long, including the Polar, Subpolar, Northern and Southern Urals. 30 mean and 8 generalized chronologies from 198 to 1010 years have been derived from the upper forest boundary along this profile (Shiyatov,1981). 32 mean and 8 generalized chronologies from 140 to 867 years have been derived from the Subarctic profile stretching for 2100 km (from the Lower Pechora river in the west to the Lower Khatanga river in the east) (Shiyatov,1972,1973,1975,1981,1984a,1984b).

Ring-width indices for these series were calculated by the curves of maximum and minimum possible increment (Shiyatov, 1972). This enables us to reveal both the short-term (intrasecular) and the long-term (secular and oversecular) fluctuations of ring-width indices. Inhomogeneity of the mean chronologies was eliminated in case of unsufficient and different number of the model trees (Shiyatov,1980).

Cycle components in the chronologies were revealed by different methods: by mooving average smoothing, by estimating autocorrelation function and its integral, by spectral analysis with linear filtration.

Repeated efforts to point out cycle components in the tree-ring chronologies and to use them in extrapolation (forecast) were unsuccesful in many cases. The reasons may be the irregularity of fluctuations in time (cyclic parameters vary and separate cycles may disappear within certain time periods), interference of cycles, poor knowledge of the nature of fluctuations, uncertain definition of the term "cycle" (Abrosov, Mazepa,1984).

Recently we have tried to use spectral presentation of stationary successions and linear filtration in estimating cycle parametres (Mazepa,1985). Spectral densities were analyzed without assumption of the parametric model producing these processes. It was assumed however, that the series, we were dealing with, were realizations of the stationary random successions. Several machine experiments were made to confirm this assumption. The following conclusions were drawn:

1. The universally known statistical methods of estimating spectral density (Blackman-Tukey method, maximum entropy method) give rather well descriptions of frequency structures of tree-ring chronologies based on the trees growing under extreme abiotic conditions. The spectra of ring-width indices for individual trees growing in different ecological conditions of one climatic region are similar. They do not significantly alter within the period 300-500 years.

2. The spectral analysis shows the existence of important narrow frequency bands with fluctuation amplitudes higher, than those of the neighbouring ones. Their widths are about 0.02-0.05 cycle/year. In case if these frequency bands are important for the majority of the tree-ring chronologies in the investigated area, they may be used as the characteristics in studies of wood increment dynamics.

Based on these conclusins we suggest the following concept of the term "cycle". By cycle we mean a component of the ring-width chronologies, which corresponds to a certain important narrow frequency band.

This concept is methodically convenient. Purposefool narrow band-pass filtration with prescribed transfer function becomes possible. Being found the important frequency bands can be analysed by choosing a corresponding filter. A linear symmetric filter with coefficients of the expansion into a truncated Fourier series by cosine of the П-shaped function was used. Successive outgoing series 9 are given in Fig.2. The spectrum for this series are shown in Fig.6.

As is known from the theory of stationary random processes, that narrow band-pass filtration of the realization of such processes being applied to outgoing series may be rather accurately approximated by a sinusoid. It is evident that the outgoing series will not be exactly periodic: two series sections separated by some extended time period are well approximated by sinusoid sections of the same frequency, but may differ in amplitude and phase.

The results of our machine experiments have shown that frequency structure of tree-ring chronologies changes rather slowly. Therefore, only important bands were used in the filtration. Outgoing series are shown by a thick line in Fig.2. They were approximated by sinusoids and the whole chronology was represented as a sum of selected sinusoids. Good approximation of the outgoing series by sinusoids was a base for extrapolation of chronology for several decades forward.

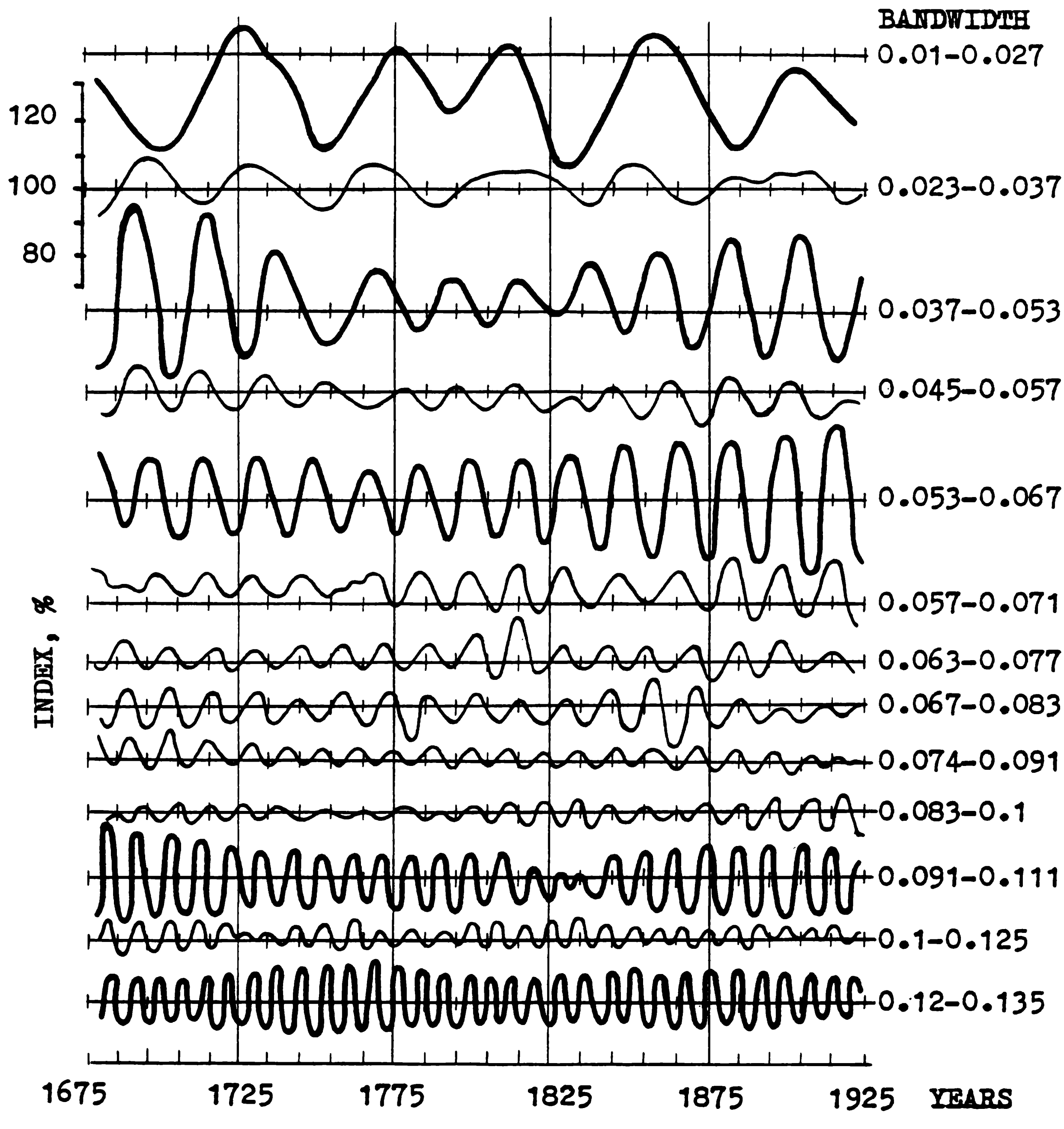


Fig.2. Successive outgoing series 9 in the band pass filtration. The thick line corresponds to impotant friquency bands, the thin line - to the intermediate ones. To the right: bandwidth (cycle/year).

Sensitivity of the tree-ring chronologies, similarity and correlation among them

The analysis of the annual ring-width indices variability has shown significant decline of the mean sensitivity from the North to the South. The chronologies of the Subarctic profile have the highest sensitivity coefficient (0.3-0.5), while those of boreal zone are only 0.2-0.3. The chronologies from the Subtropical zone are still less sensitive (Table 1). This is due to lesser climate variability in the direction from the North sea coast to the South, at the upper boundary of the forest stands in particular. The most sensitive are the chronologies of the larch, the chronologies for dark-needled forests are the least sensitive.

The coefficient of the synchronization among the chronologies obtained from the same climatic region can be high. This is especially typical for the Subarctical areas. For example, in the Polar Urals it changes from 70 to 95%, while in the Southern Urals the value is 53-88%. In the northern regions the synchronization among the series is preserved at a distance of 500-600 km. Synchronous fluctuations in the ring-width indices are obtained in the vast area covering the West-Sibirian forest-tundra, Polar, Subpolar and Northern Urals. Synchronization among the chronologies for the Polar and Southern Urals, for the Urals and Taimyr peninsula is lacking. Correlation coefficient changes similarly.

Thus the climatic limiting factors are showing up most vividly in the Subarctic regiöns. The most reliable climatic reconstructions are possible there. This suggestion is proved by the fact, that the chronologies of the same tree species growing in the different habitat types (from dry to swampy) have high similarity and synchronization values.

Reconstruction of the summer thermal conditions

Air temperatures of the summer months, June and July especially, are the main growth limiting factors at the upper and polar boundaries of the forests. The correlation coefficients between the thermal regime and ring-width indices are 0.6-0.8 in the northern regions and 0.4-0.5 in the southern ones (Polozova, Shiyatov,1975,1979; Mazepa,1982). Thus the reconstructions of the summer air temperature for the northern Urals provinces and the Lower Taz river were made by the regression equations (Fig.3). During the latest 250-1000 years the significant thermal fluctuations were observed. The mean summer temperatures at the upper forest boundary during the separate 5-year periods ranged from 8.7 to 11.0° in the Polar Urals, from 8.9 to 10.1° in the Subpolar Urals, from 9.1 to 10.5° in the Northern Urals. For some years the range of the variability of the summer temperatures was much higher. Attention is drown to the marked temperature rise in the X-XIV centuries, called the Little Climatic Optimum. The upper forest boundary in the Polar Urals was 80-120 m higher at that time than at present (Shiyatov,1979). In the XV-XIX centuries the climate was colder and wetter (the Little Ice Age), since the 20's of the XX century it became warmer. Against the background of these long-term climatic changes shorter fluctuations are traced. XIII, XVI, XVIII and XX centuries were the warmest, XV, XVII and XIX centuries were the coldest ones.

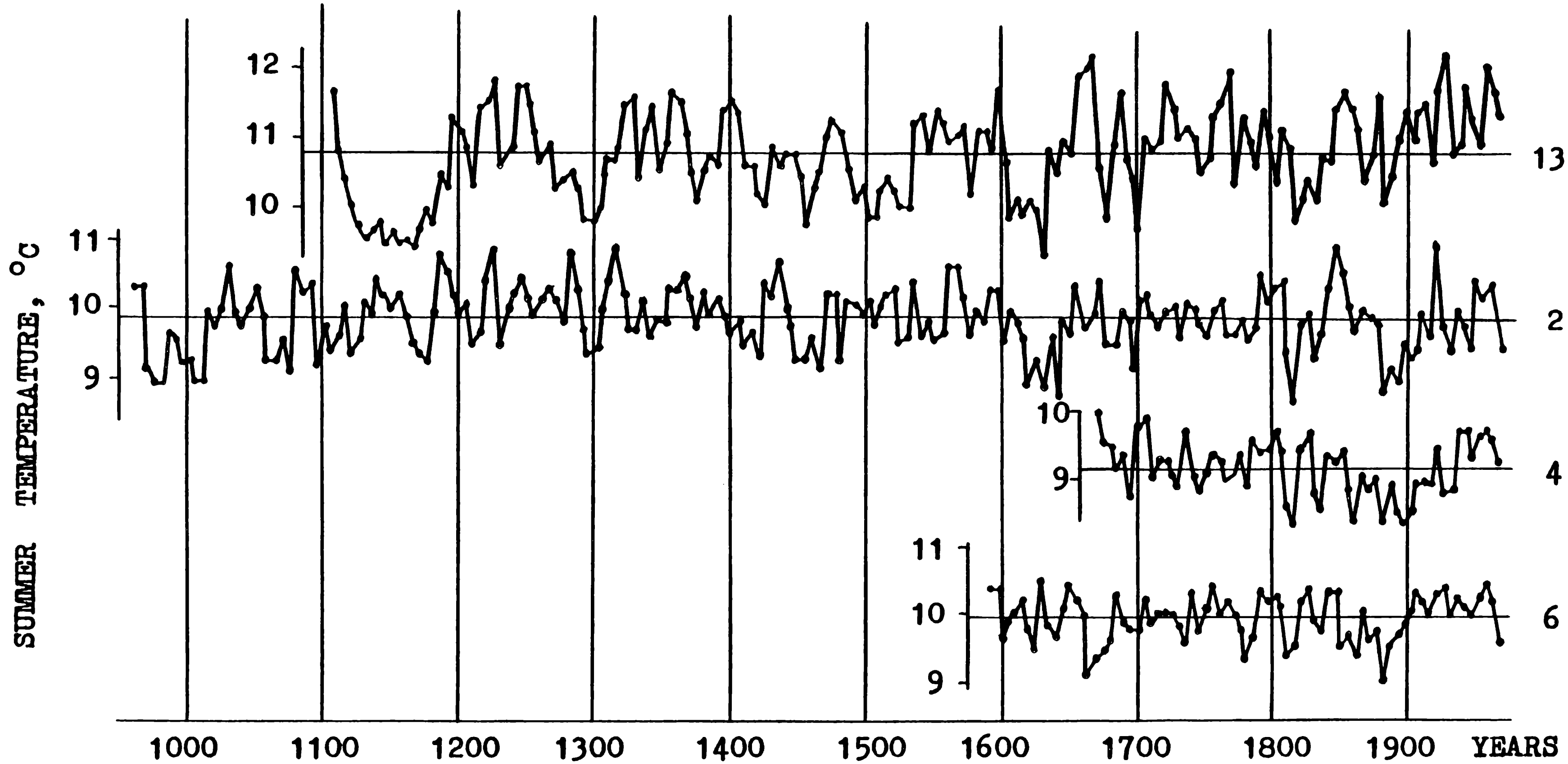


Fig.3. Reconstructed summer temperatures for the Lower Taz river (13), the Polar Urals (2), the Subpolar Urals (4), the Northern Urals (6).

Cycles in the tree-width indices variation

Interest in the cyclic tree-ring fluctuations is associated with the possibility to use them in the forecasts. Up to now the short-term cycles were more or less throughly studied, the investigation of the long-term cycles have just begun. The cycles are usually subdivided into intrasecular (from 2 to 60 years), secular (from 60 to 120 years) and oversecular (over 120 years).

Oversecular cycles. The cycles of this duration are the most dificult to be pointed out in the tree-ring chronologies. The reasons are: the comparatively short life span of trees (no more than 300-500 years usually) and elimination of the largest cycles in converting absolute ring-width values to relative ones. Such cycles have been revealed only in the longest chronologies, obtained for the Urals and West-Sibirian forest-tundra (Fig.4). The double secular cycle of 160-180 years is shown up in the series 2 (the Polar Urals) and in the series 13 (the Lower Taz river). 200-300 years cycles were revealed only in some series. However their parameters were consedered to be unsufficient , becouse they were repeated only once or twice in the series.

Secular cycles. The length of the most obtained chronologies is enough to reveal the secular cycles. Fig.4 shows 55-60 years cycle in the series 2, 10, 11 and 12. It is seen from this figure that the secular cycle is synchronous in different tree species (Pinus sibirica, Larix sibirica and Picea obovata) and as the distance of 600 km from one another. 55-60 years cycle was revealed almost in all series of the Urals high mountains and the Subarctic profile. Many series of the

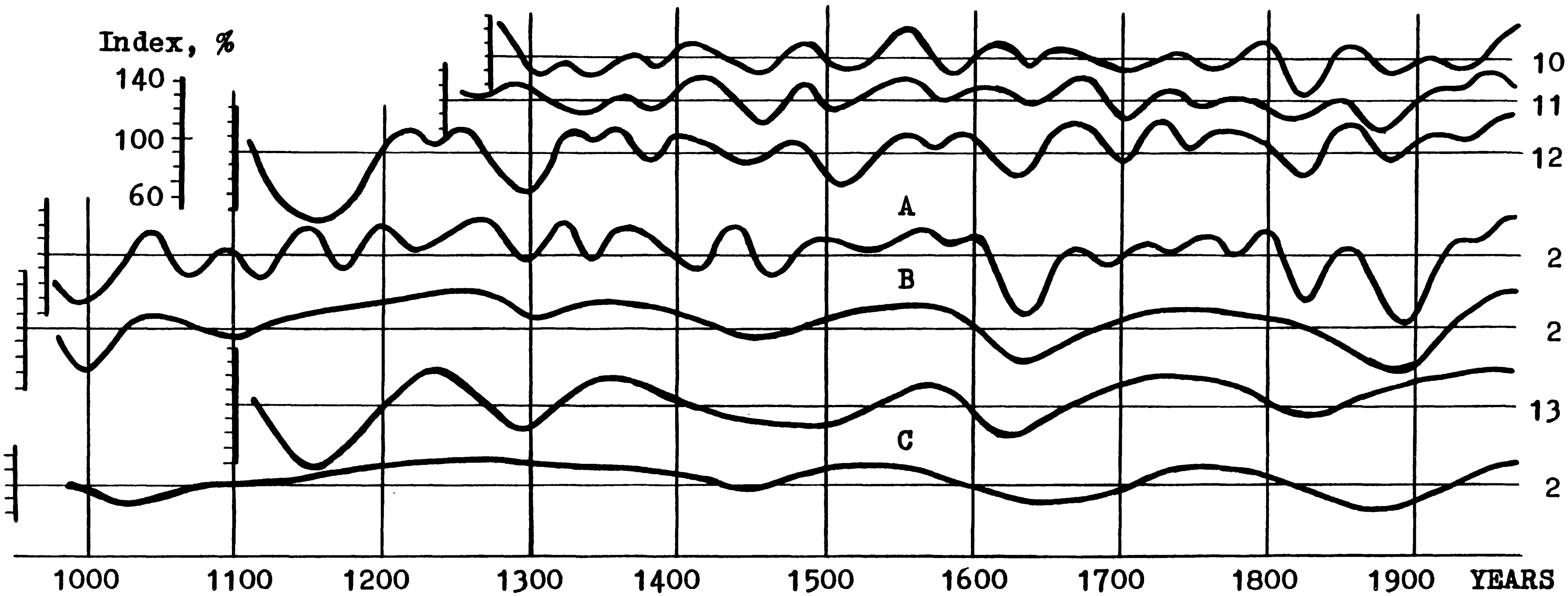


Fig.4. The secular and oversecular cycles of tree-ring indices for Larix sibirica (2,12,13), Picea obovata (11), Pinus sibirica (10) in the Polar Urals and the Lower Taz river. The curves A,B and C obtained by mooving average smoothing of 30-, 50- and 110 years respectively.

northern regions have the cycle of 110-120 years long. 80-90 years cycle was observed only in some series. High synchronization of the secular cycles was noted for different tree species, growing under varios habitat types of the Subarctic, this synchronization is preserved in distant areas. Amplitude of these cycles declines from the North to the South. The chronologies of larch show up the greatest synchronization possible in secular cycles. The least synchronization is observed in series of Sibirian fir and Sibirian cedar.

Intrasecular_cycles. The most detailed analysis of the intrasecular cycles was made in the Urals high mountains profile. We managed to follow the changes in the tree-ring cycles in different species and different habitats. The spectra for different chronologies of Sibirian larch are given in Fig.5.

The analysis of the cycle components shows that a number of cycles in different Urals provinces is dissimilar. The number of cycles increases from the Polar to the Southern Urals. The majority of the cycles is common to all provinces, 70-90% of all series investigated, have common cycles. The following cycles are wide spread and common to the Urals highlands: 21-24, 16-18, 10.0-11.5, 5.3-6.0, 3.9-4.4, 3.3-3.7, 2.8-3.1, 2.1-2.2 years. Some cycles are revealed mainly or specifically within one or two Urals provinces. For example, the cycles of 7.5-8.4 and 4.6-5.0 years are typical for the Southern Urals, the cycles of 41-45 and 36-39 years are characteristic of the Subpolar and Northern Urals, 12-14 years cycle is peculiar to the Northern and Southern Urals.

There are cycles manifesting themselves predominantly in the chronologies of particular tree species. Thus, the chro-

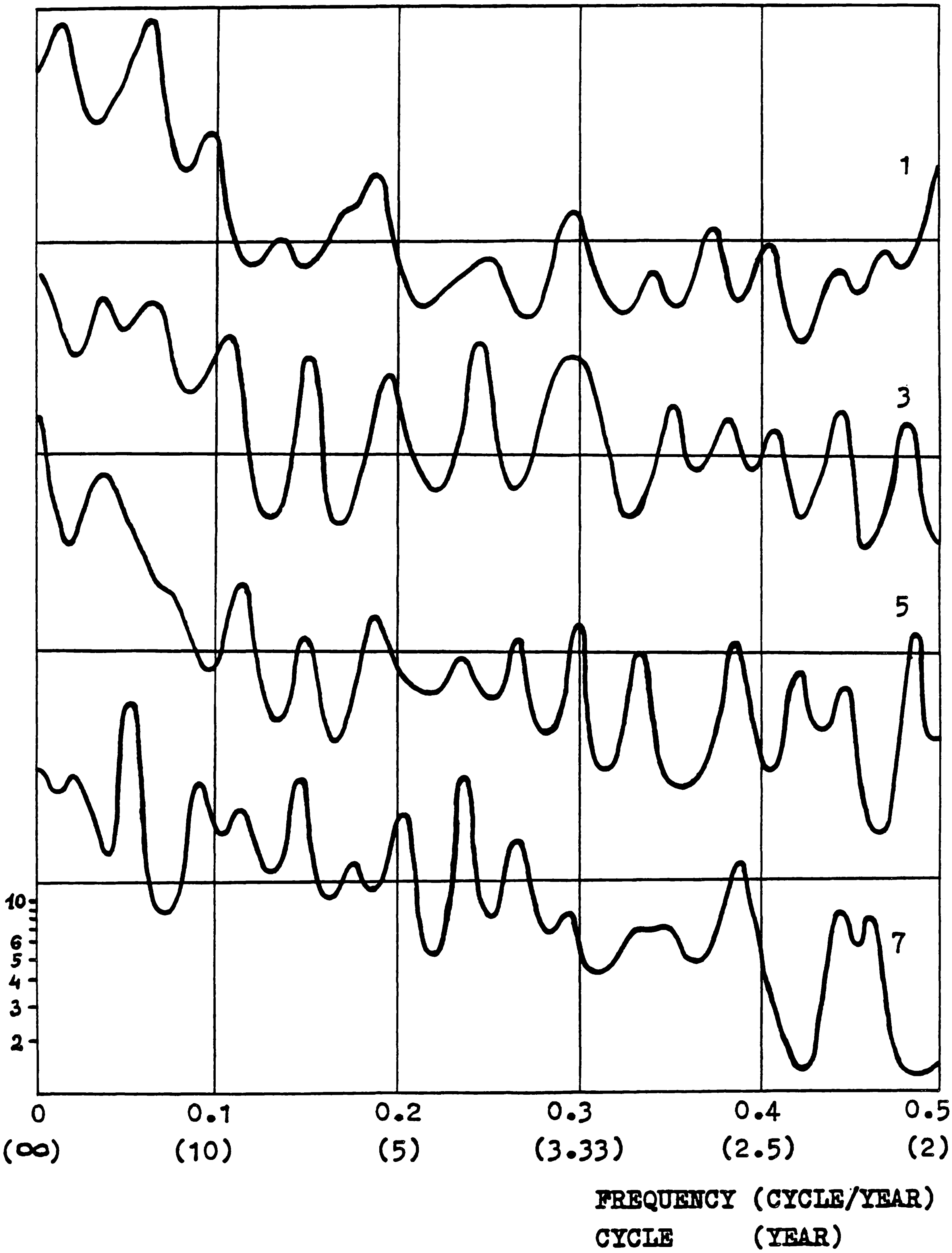


Fig.5. Spectra for the chronologies 1, 3, 5 and 7.
The Urals profile.

nologies of the common pine have the 32-34 years cycle, those of the Sibirian fir exibit the 41-45 and 12-14 years cycles, those of the Sibirian larch reveal the 16-18 years cycle. The environment does not practically influence the number of the cycle components in the chronologies, derived from the Polar, Subpolar and Northern Urals, but they do effects in the Southern Urals high mountains, where the role of the limiting climatic factors is diminished.

The cross-spectral analysis of the chronologies for the Urals profile has shown that there is a close correlation among the series of the Sibirian larch. This evidences its greater sensitivity to environmental fluctuations, especially for the climatic variations, as compared with the Sibirian fir and common pine. The chronologies of the Sibirian fir were observed to have lagged of some cycles compared with the chronologies of the Sibirian larch.

The highest correlations among the chronologies and cycles were received for the Polar Urals and West-Sibirian forest-tundra. They gradually decline toward the South.

According to the number and correlation among the cycles, as well as the synchronization among the chronologies the Urals highlands can be subdivided into two areas: the northern region, covering the Polar, Subpolar and Northern Urals, and the southern region including the Southern Urals only.

The cyclic components in the tree-ring chronologies for Sibiria, Middle Asia and Far East are revealed in the separate chronologies. The spectra for these chronologies are given in Fig.6 and 7.

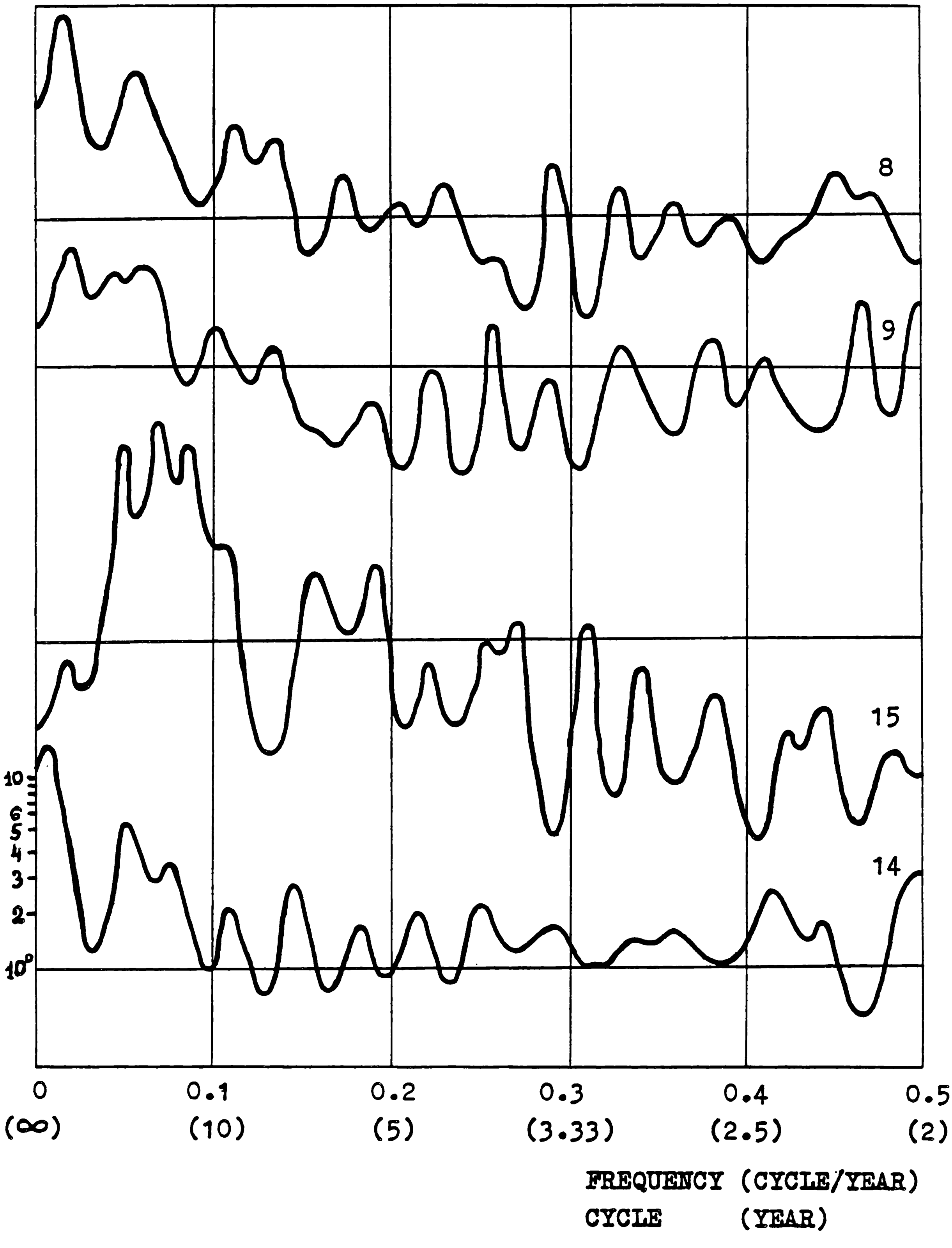


Fig.6. Spectra for the chronologies 8, 9, 15 and 14.
The Subarctic profile.

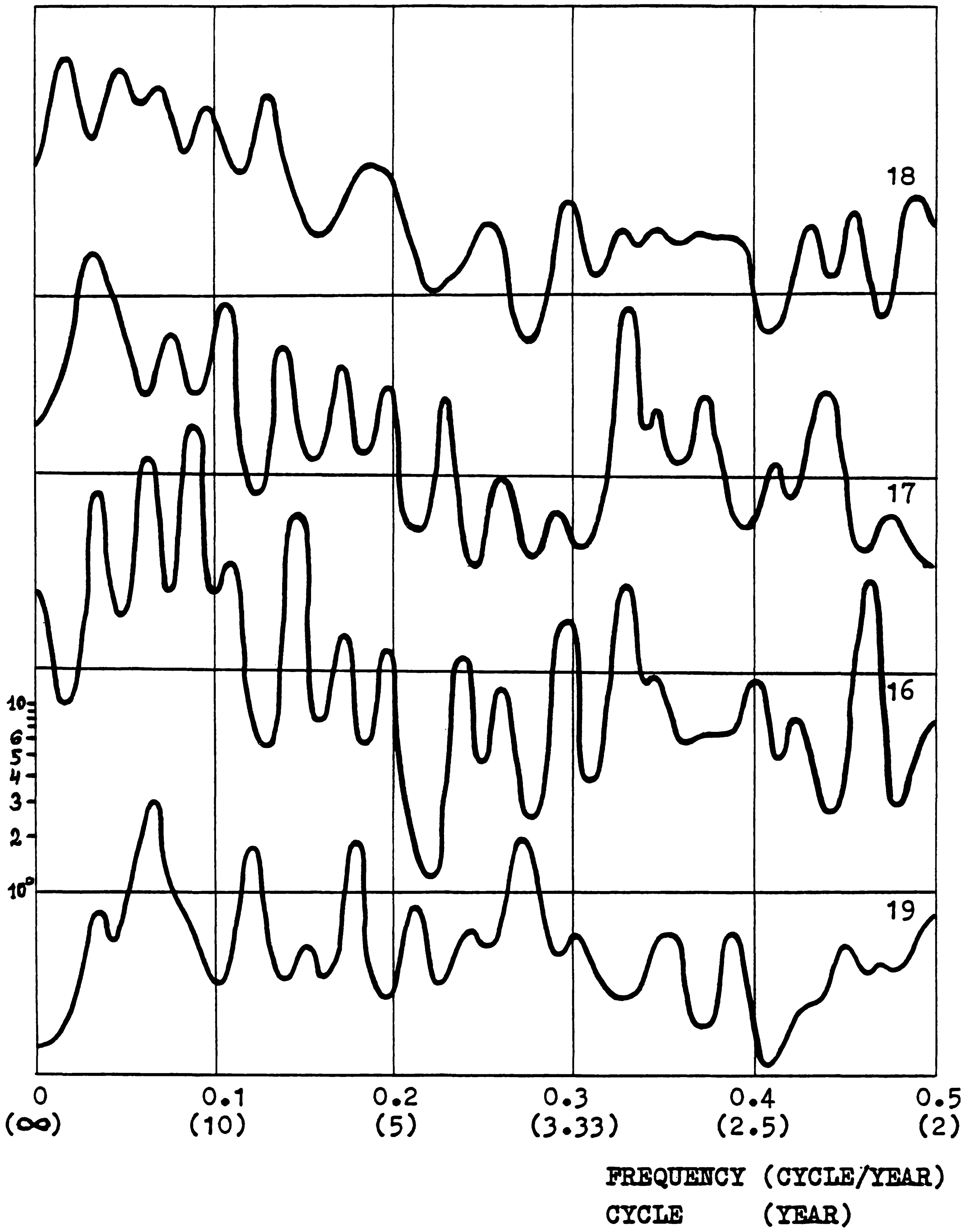


Fig.7. Spectra for the chronologies 18 (Kungey Alatau), 17 (Zailiyskiy Alatau), 16 (Khamar-Daban) and 19 (Kamchatka).

Approximation of the tree-ring chronologies by the sum of sinusoids and the forecast

The calculations have shown that a mean-root-square error for the sinusoidal approximation of an individual cycle ranges from 3 to 10 units, most frequently the error is 5 or 6. The final chronologies sections and their approximations by a sum of sinusoids are plotted in Fig.8-11. The correlation coefficient and mean-root square errors show approximation quality. To our point of view the similarity between the original and the approximated series is satisfactory. Assuming the comparatively stable increment dynamics, we produce quantative forecast for 30-50 years. However, we realize that the polyharmonic model is not quate appropriate for describing the relative wood increment process owing to its stable periods.

Connected with long-term plans of natural resources usage and preservation, forecasting is essential. The analysis of cycles helps to forecast climate caused increment dynamics of the trees growing in extremal abiotic conditions. Besides such analysis helps to estimate global anthropogenic impacts on vegetation cover , judjing by the sharp disturbancies in the frequency structure dendrochronological series. However, it should be noted, that the analysed chronologies are based on the model trees living in undisturbed areas. Therefore the observed changes are caused by natural climatic fluctuations of the wood increment dynamics.

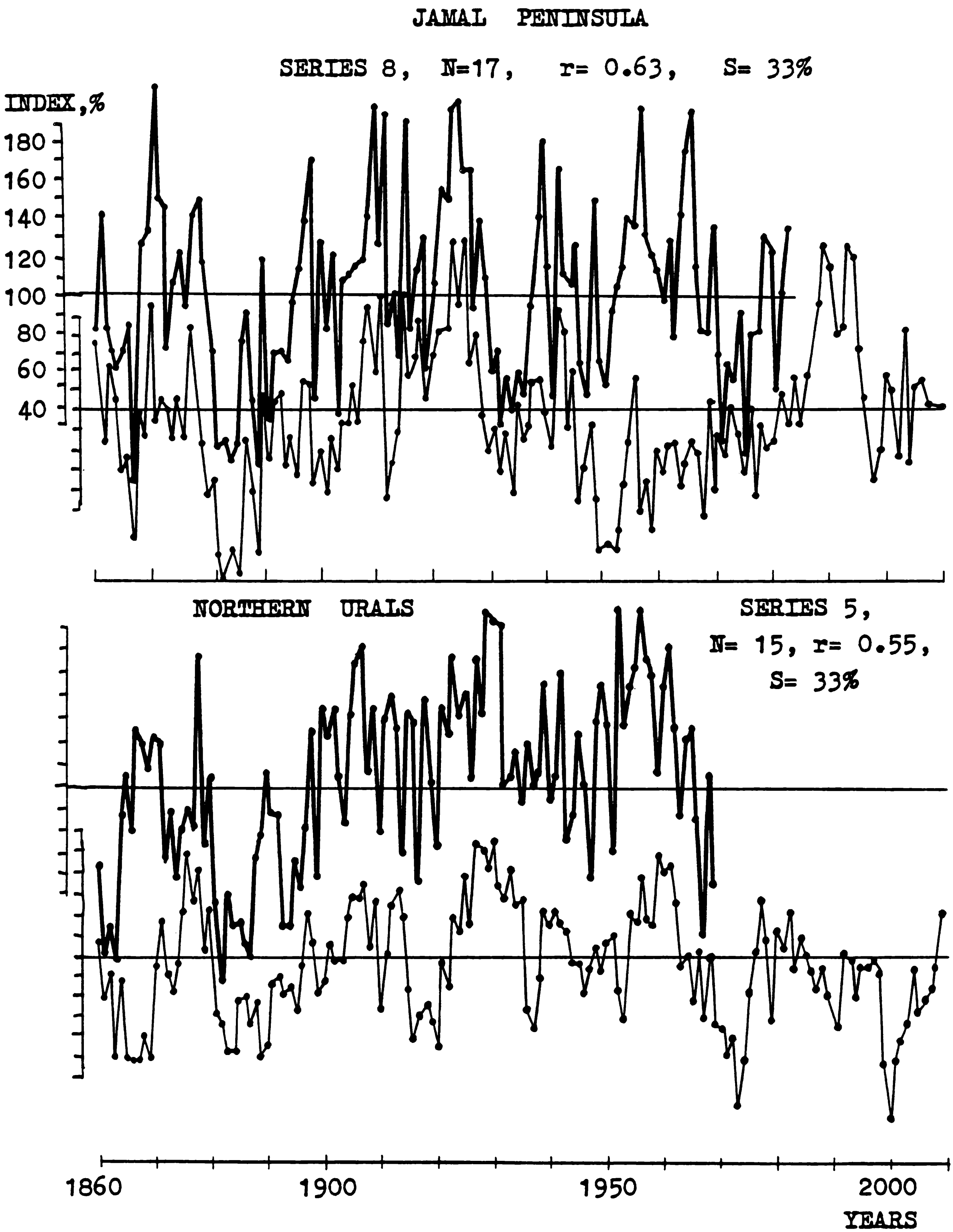


Fig.8. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

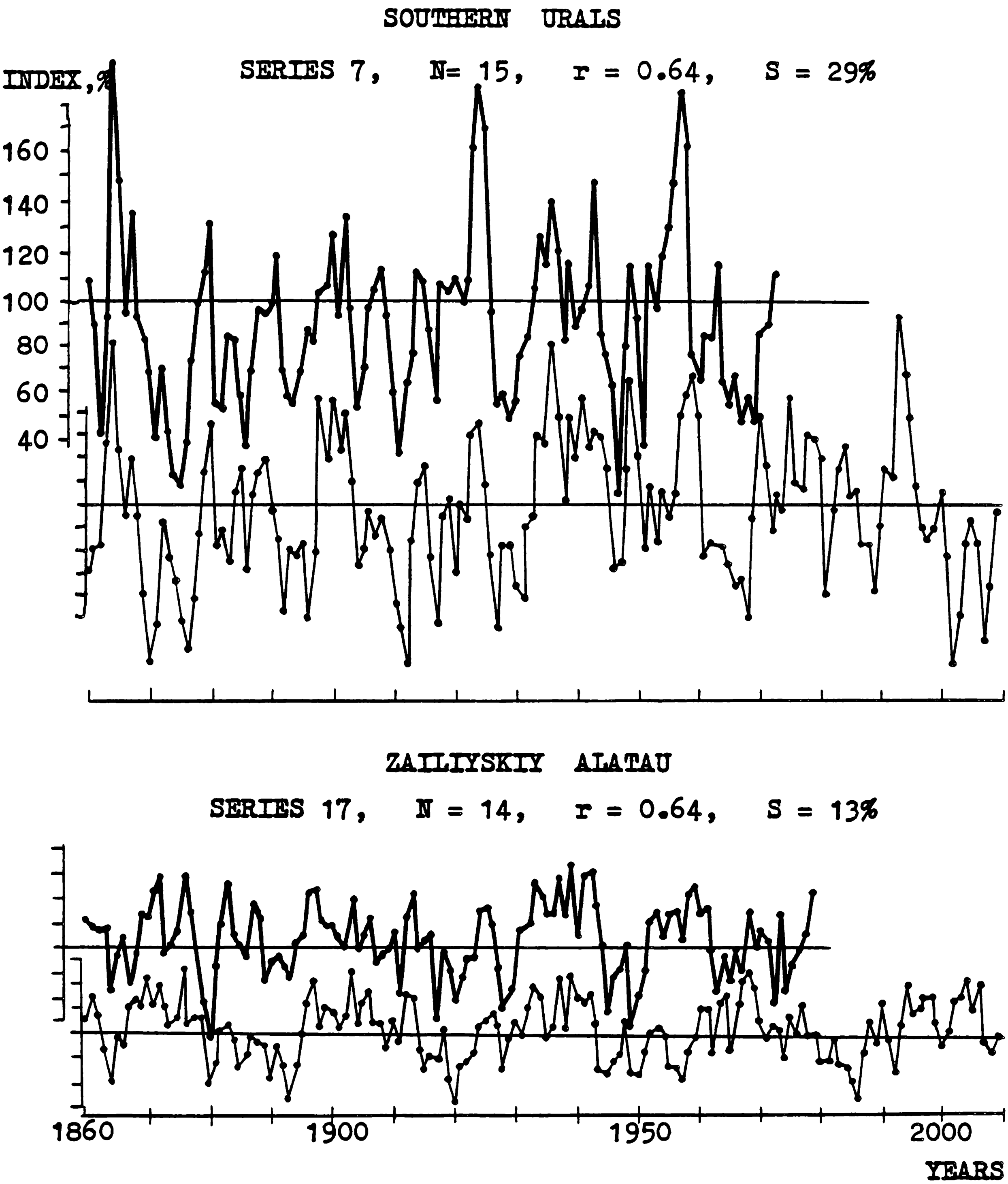


Fig.9. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

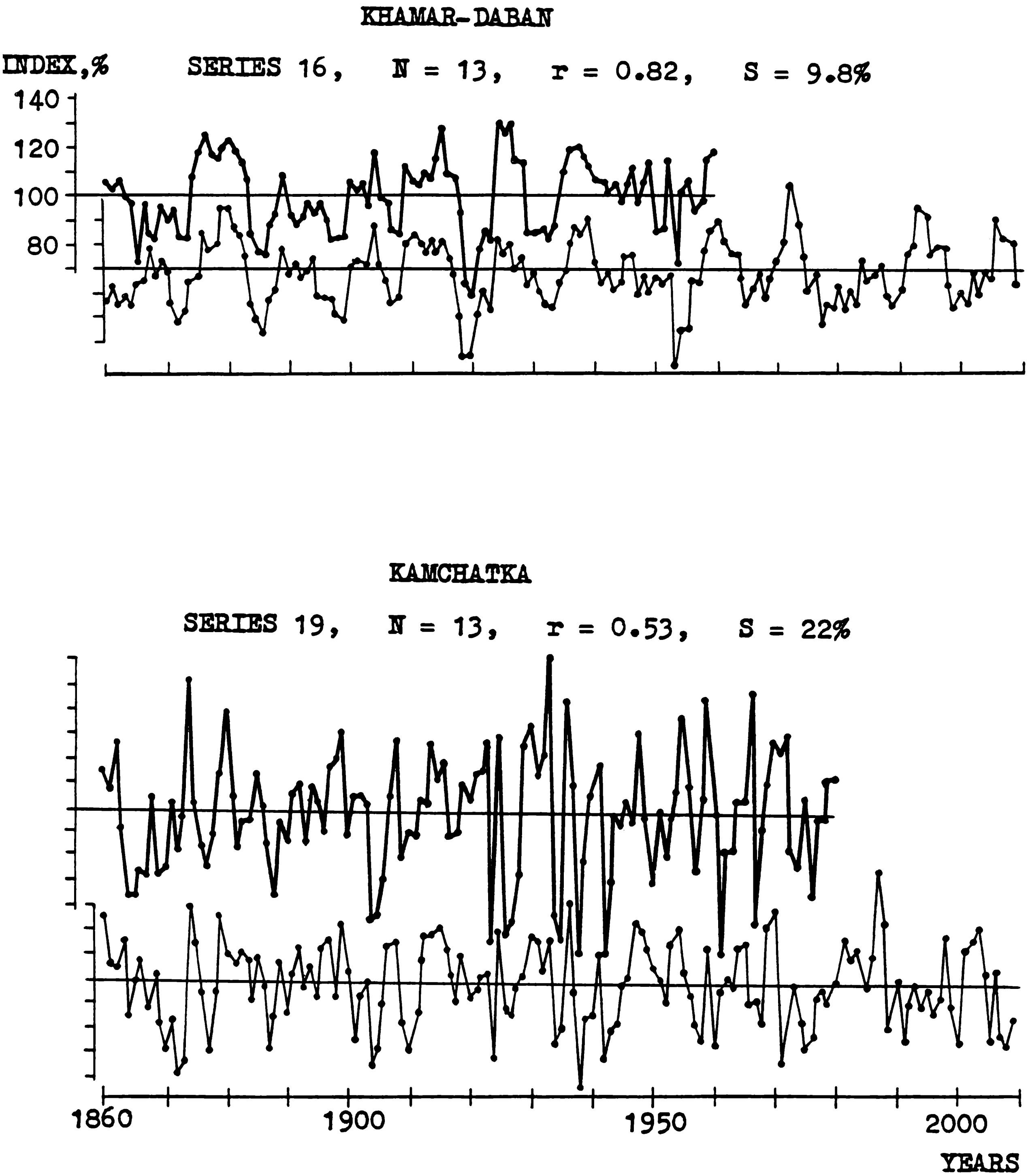


Fig.10. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

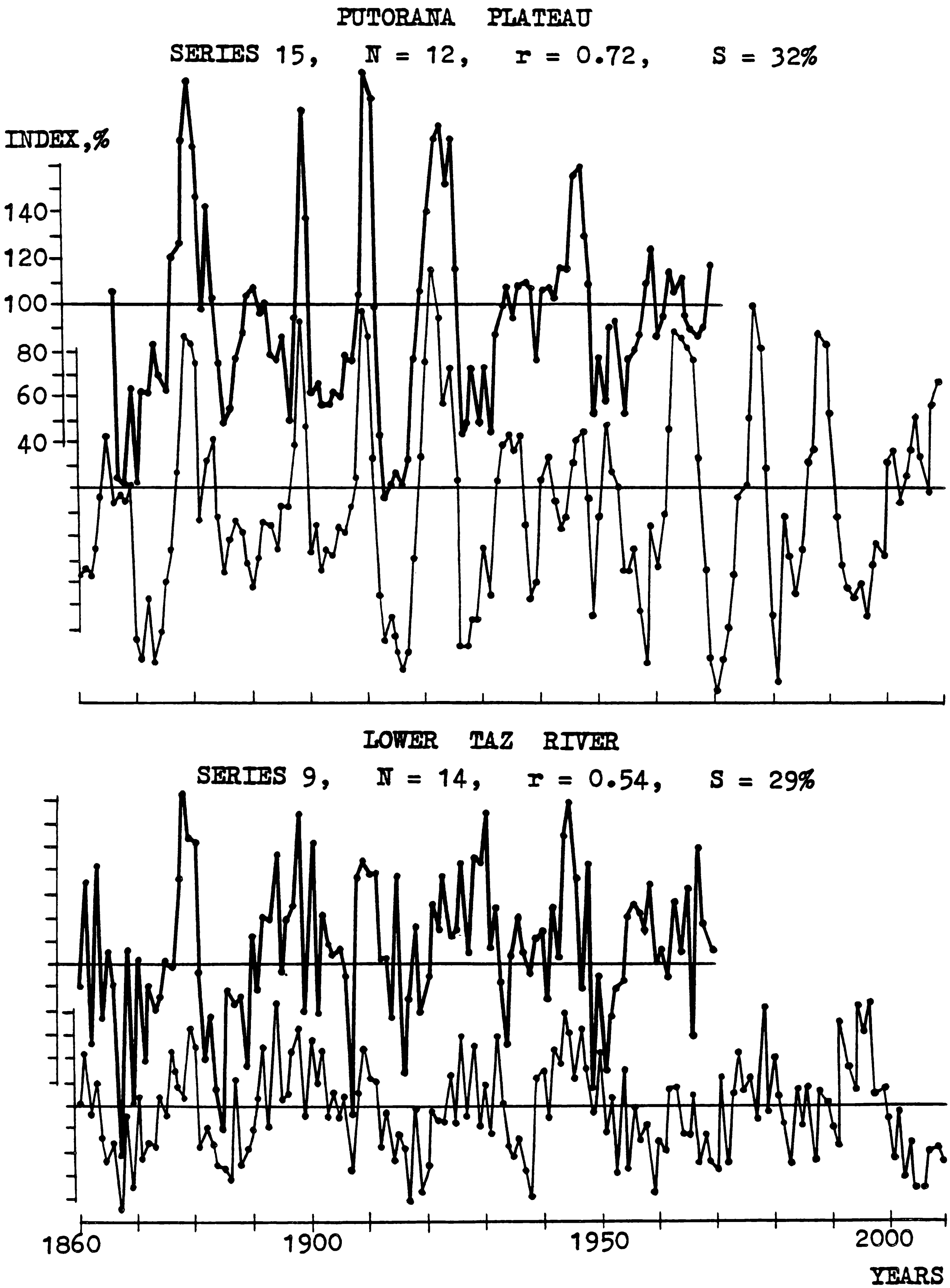


Fig.11. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

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