AN ANALYSIS OF VARIATION IN TREE-RINGS: APPLICATION OF POISSON'S CYCLIC PROCESS FOR CLIMATIC PROGNOSES

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Abstract

Tree growth is frequently affected by favourable and unfavourable conditions of climate background which are reflected by some cyclic fluctuations in dendroscales. In the paper an analysis of dendroscales spanning 134-175 and 867 years is presented. By using the cyclic models of intensity of the Poisson's law of random events of a natural phenomenon long term (176, 357, 65 years in duration) cycles in dendroscales have been stated. A long with the short term fluctuations of tree growth, long duration of "good" and "bad" years for tree growth has been stated and prognoses for nearest future established.

Keywords: Dendrochronology, increment index, cyclic components, prognoses

INTRODUCTION

Recently the scientific community became seriously concerned about global changes occurring in the biosphere, which can cause planetary emergencies. In order to understand environmental changes exeeding the natural limits yearly fluctuations and these occurring over: decades or even centures are of particular importance to look into our past as far as it is possible. One of such possibilities is the studies of tree rings (Fritts,1987). Tree growth is frequently affected by climatic variation and the yearly sequence of favourable and unfavourable climate conditions is faithfully recorded by the sequence of wide and narrow rings in a large number of trees.

A great deal of investigators have analysed cycles in the series of dendrochronological indices and their relationship between the processes occurring in the environment. Most investigators have stated that the dynamics of dendrochronological indices z_t is rather well reflected by the cyclic model (Shijatov, Mazepa, 1987; Kairiukstis, Dubinskaite, 1986; Lovelijus, 1997; Mazepa, 1986; Beri, Lieberman, Shijatov, 1979):

$$z_t = A_0 + \sum_{j=1}^{n} A_j \cos(2\pi t / T_j + \varphi_j) + \varepsilon_t,$$

t=1, 2, ... m, where m refers to dendroscale length, ε_t is a stationary random process, A_0 - the average value of indices, A_j, φ_j - the amplitude and phase of periodic fluctuation j in period T_j, n - the number of periodic components. In the dendroscale most investigators (Mazepa, 1986; Shijatov, 1987; Stravinskiene, Vencloviene, 1998) have stated fluctuations of cyclic parameters - amplitudes, phases and cycle length. It is hoped that these parameters also vary in a cyclic way and the length of cycles of their variation reflects certain processes occurring in the Universe. Let us analyse the peculiarities of the dynamics of amplitudes of short term cyclic fluctuations in Lithuanian dendroscales.

MATERIAL AND METHODS

For the analysis of the dynamics of short term cycles three dendroscales of 134-175 years in duration have been used (Brukstus, 1987; Bitvinskas, Brukstus, 1987): two dendroscales of pine stands growing on *Vaccinium - myrtillus* sites of normal moisture (Fig. 1, a, b) as well as a dendroscale of spruce stands growing on moist *Caricoso - sphagnosum* sites (Fig. 1, c). Also for evaluation of ecoclimatic background the dendroscale from the polar limits of forest growth (constructed by S. Shiatov (1975)) of Larix sibirica, which spans a long cycles (1103-1960), has been applied.

The dynamics of indices series z_t, *t=1,2,...,n* which vary in cyclic amplitudes of cyclic fluctuation the following model is used:

$$z_t = A_0 + \sum_{j=1}^{n} A_j(t)\cos(2\pi t / T_j) + \varphi_j) + \varepsilon_t,$$

where $A_j(t)$ - the function describing a variation in the amplitudes of fluctuations. Function $A_j(t)$ may be periodic

$$A_j(t) = \alpha_j(1 + \cos(2\pi t / T_{1j})) \qquad \text{or } A_j(t) = \alpha_j|\cos(2\pi t / T_{1j})|$$

where T_{1j} >> T_j (the period of amplitude fluctuation is by far longer than the cyclic fluctuation length itself),

$$A_j(t) = \alpha_j \cos(\pi t / T_{1j}) \qquad (*)$$

where $T_{1j} >> T_j$. In this case not only the amplitude of cyclic fluctuation varies periodically but also the phase. It is noted that direct determination of periodic T_{1j} of fluctuations $A_j(t)$ in series z_t is infeasible by the methods of the sliding mean and spectral or harmonic analysis. In narrow bands of frequency $1/T_j$ (or period T_j) density spectrum of function

$$A_j(t)\cos(2\pi t / T_j + \psi_j),$$

where $A_j(t)$ has been determined by previously presented formulae and $T_{1j} >> T_j$, will posses several peaks and be insignificant for the periods close to T_{1j} (or low frequencies).

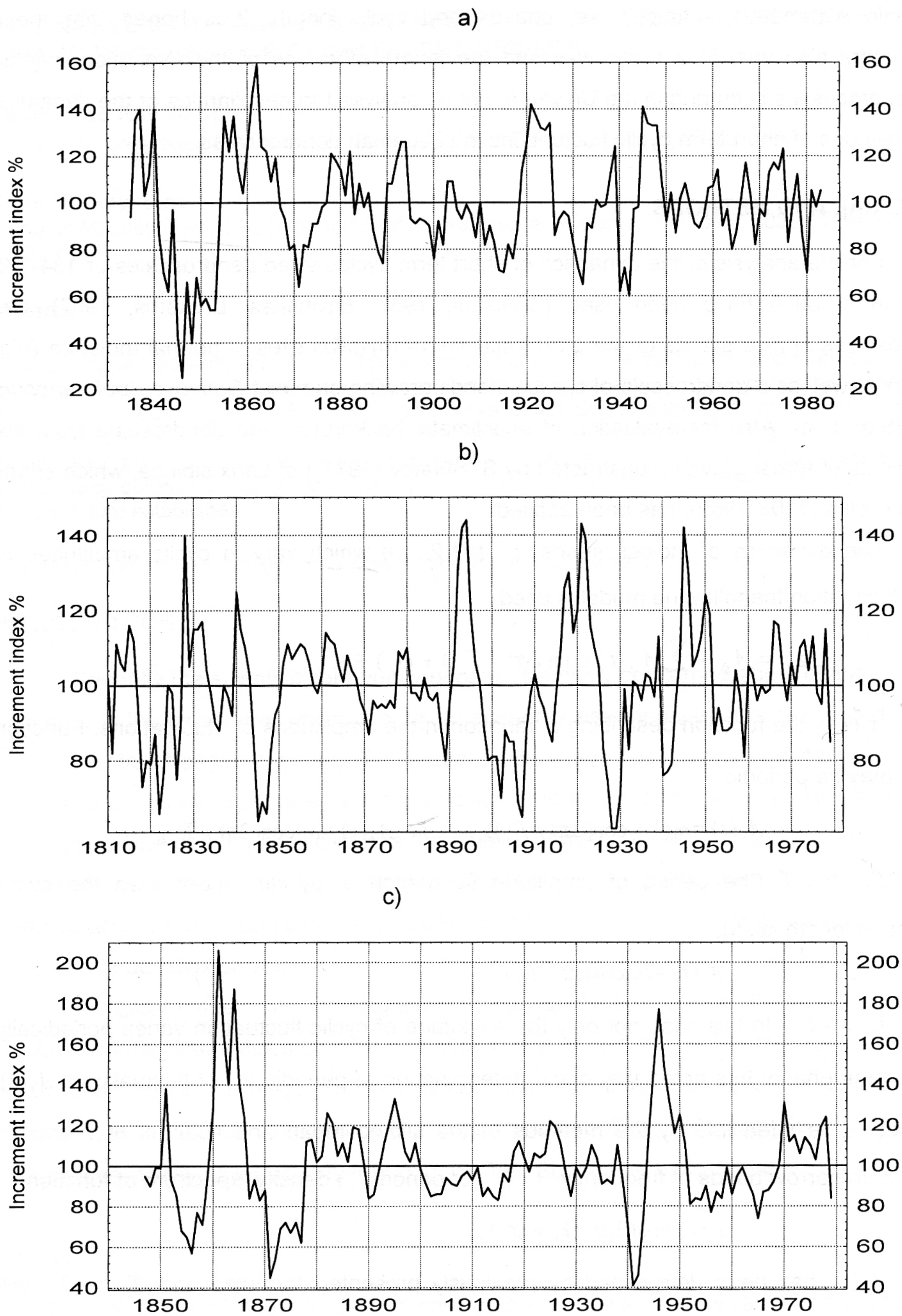

Figure 1. The standard chronology of pine stands growing on *Vaccinium - myrtillus* sites of normal moisture (a), (b) and standard chronology of Spruce stands growing in the soils of surplus moisture (c)

We see that density spectrum of function

$$y(t) = 4.5\cos(\pi t / 60)\cos(2\pi t / 11 + 2.1),$$

where *t=1,…,350* (Fig. 2) possesses two peaks in frequencies 0.083 and 0.101 or in periods 12 and 9.94. For frequencies lower than 0.75 or for periods longer than 20, spectral density of this function is insignificant. Function *y(t)* is an individual case of function z_t, where $A_j(t)$ has been determined by (*) formula.

Given the expression of function *y(t)* and having frequencies v_1 and v_2, in which there are peaks of spectral density, we can calculate the values of T_{11} and T_1. However, in case time series analysed by us is the sum of several cyclic components and random noise the problems arise in determining cycles of a variation in amplitudes according to the peaks of spectral density. Therefore, in order to elucidate the period of function $A_j(t)$ instead of studying function $A_j(t)\cos(2\pi t / T_j + \psi_j)$ function $|A_j(t)\cos(2\pi t / T_j + \psi_j)|$ - the absolute deviation of this function from the centres of fluctuations must be analysed. The spectral density of function |*y(t)*| (Fig. 3) possesses distinct peaks in frequencies 0.017 and 0.18, or in periods 58 and 5.5. By applying harmonic analysis it has been asertained that peak 58 corresponds to a period of 60 years. While analysing the above example we can state that for determination of a cycle of amplitude fluctuation of cyclic components instead of studying time series z_t by the methods of spectral and harmonic analysis transformed time series $\bar{\bar{z}}_t = |z_t - \bar{z}_t|$ must be analysed.

In order to evaluate and predict background ecoclimatic tendencies over centuries the indices of series have been filtered by low band filter (the sliding of 101 year). Then in the series cyclic components and their parameters are determined by the methods of harmonic and spectral analysis. With the aid of these parameters the background ecoclimate is predicted. We will assess the background ecoclimate only by using the values which considerably differ from the average value of indices series $\bar{x}$, i. e. which do not get into the interval $\bar{x} \pm \sigma$, where σ - the standard deviation of indices series.

There are reasons to think that within interval t±50 years numbers $n_+(t)$ and $n_-(t)$ of years of “good” and “bad” conditions for the growth are random but associated with certain processes occurring in the environment. The conditions are considered to be “good” for the growth in case index of the increment exceeds $\bar{x}+\sigma$ and “bad” in case it is lower than $\bar{x}-\sigma$. It is hoped that the number of these seldom occurring events varies according to the Poisson’s law with intensities $\lambda_+(t)$ and $\lambda_-(t)$:

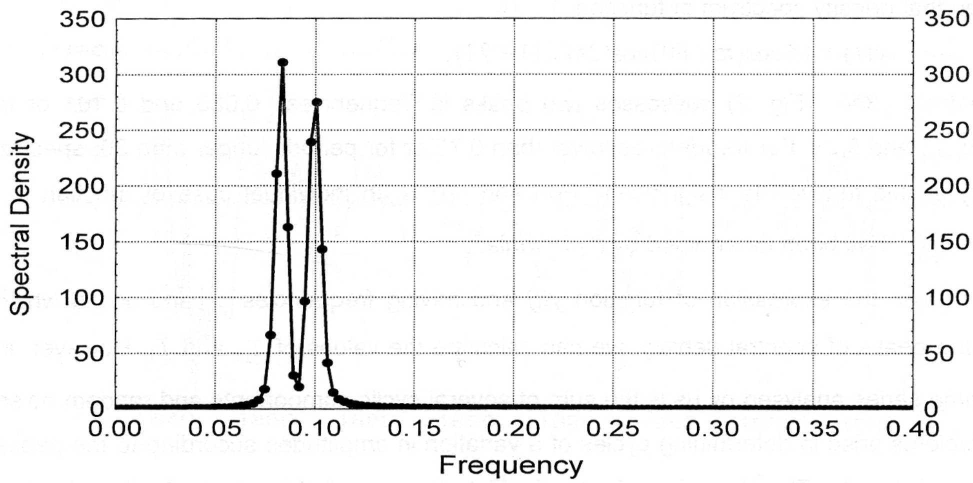

Figure 2. Spectral density of function Y(t)=4.5×cos(πt/60) ×cos(2πt/11+2.1)

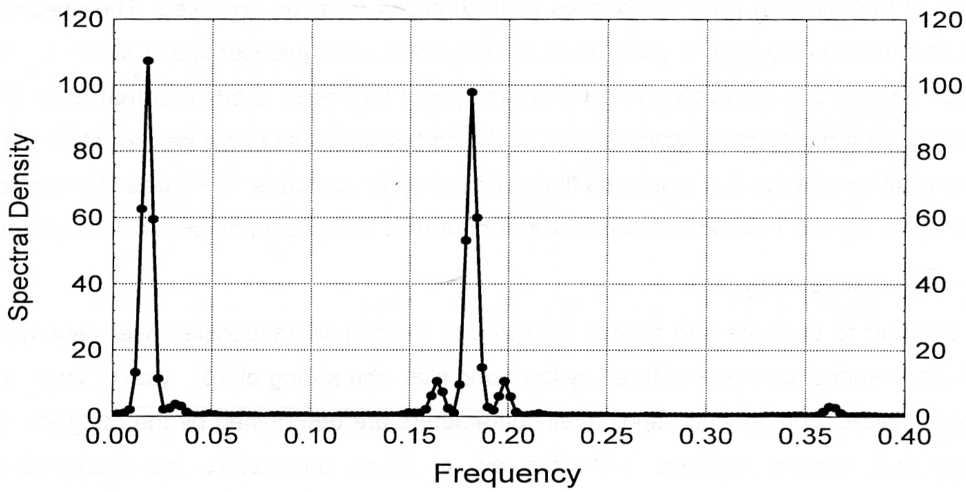

Figure 3. Spectral density of function |Y(t)|

$$P\{ n_+(t)=k\}=(\lambda_+(t))^k exp\{-\lambda_+(t)\}/k!,$$

$$P\{ n_-(t)=k\}=(\lambda_-(t))^k exp\{-\lambda_-(t)\}/k!,$$

With the help of this law, which is called the law of random events other natural phenomena such as the number of earth-quakes in a certain period has been explained. The dynamics of the numbers of "good" and "bad" conditions throughout a century may be considered to be Poisson's processes with intensities $\lambda_+(t)$ and $\lambda_-(t)$. Intensities $\lambda_+(t)$ and $\lambda_-(t)$ are estimated by $n_+(t)$ and $n_-(t)$. The general ecoclimatic background will be reflected by the difference in intensities $n_+(t)$-$n_-(t)$. We suggest that the general ecoclimatic background should be evaluated by this function because while constructing a series of indices from the absolute increment series the general tendency of a decrease or an increase in the increment will be eliminated by intercepting the influence of growth trend. It is more difficult to level distinct values resulting from the changes in the general ecoclimatic background.

RESULTS AND DISCUSION

It is observed even visually that fluctuations of 11 - 14 year and 21-24 year cycles of three dendroscales of 134-175 years in duration are non-stationary: fluctuations near the average values occur with larger or smaller amplitudes (Fig. 1). In the periods 1835-1870 and in 1935-1950 in all dendroscales of pine stands an increase in the amplitudes of fluctuations is noted whilst in the periods 1871-1900 and in 1952-1980 a decrease in them. The dynamics of amplitude fluctuation of the indices of spruce stands is similar. Fluctuations of amplitudes approximately recur every 100 years. In density spectra of all dendroscales the peaks are very distinct, which correspond to the main fluctuation cycles of 11-14, 21-24 and 29-30 years. In these dendroscales longer cycles have not been detected by spectral or harmonic analysis.

In order to determine the cycles of amplitude fluctuation instead of studying series z_t of dendroscale indexes the absolute deviation from the average of series $\overline{\overline{z}}_t = |z_t - \overline{z}_t|$ or transformed indexes will be analysed (Fig.4). The values of spectral density of series z_t, which correspond to the periods larger than 40, were insignificant whereas these of spectral density of series $\overline{\overline{z}}_t$, which correspond to the same periods were significant (Fig. 5). It corroborates the assumption that in series $\overline{\overline{z}}_t$ long cycles hide. They are longer than half length of the series.

For assessment of the cycles of such length by the methods of harmonic and spectral analysis the above illustrated series of dendroscale indices are too short. Such cycles can be more reliably revealed by the method of the sliding mean with the sliding of 21 years.

While analysing long term cycles for assessment of the last decade a prediction of indices of these series, which is made with the help of a cyclic model also has been applied. It appeared that in the sliding of transformed indices of pine and spruce stands growing in the soils of normal moisture as well as in these of spruce stands growing in humid soils long cycles of amplitude fluctuation of increment indices explicitly singled out (Fig. 6). The least fluctuations of the increments were observed in the period 1870-1890.

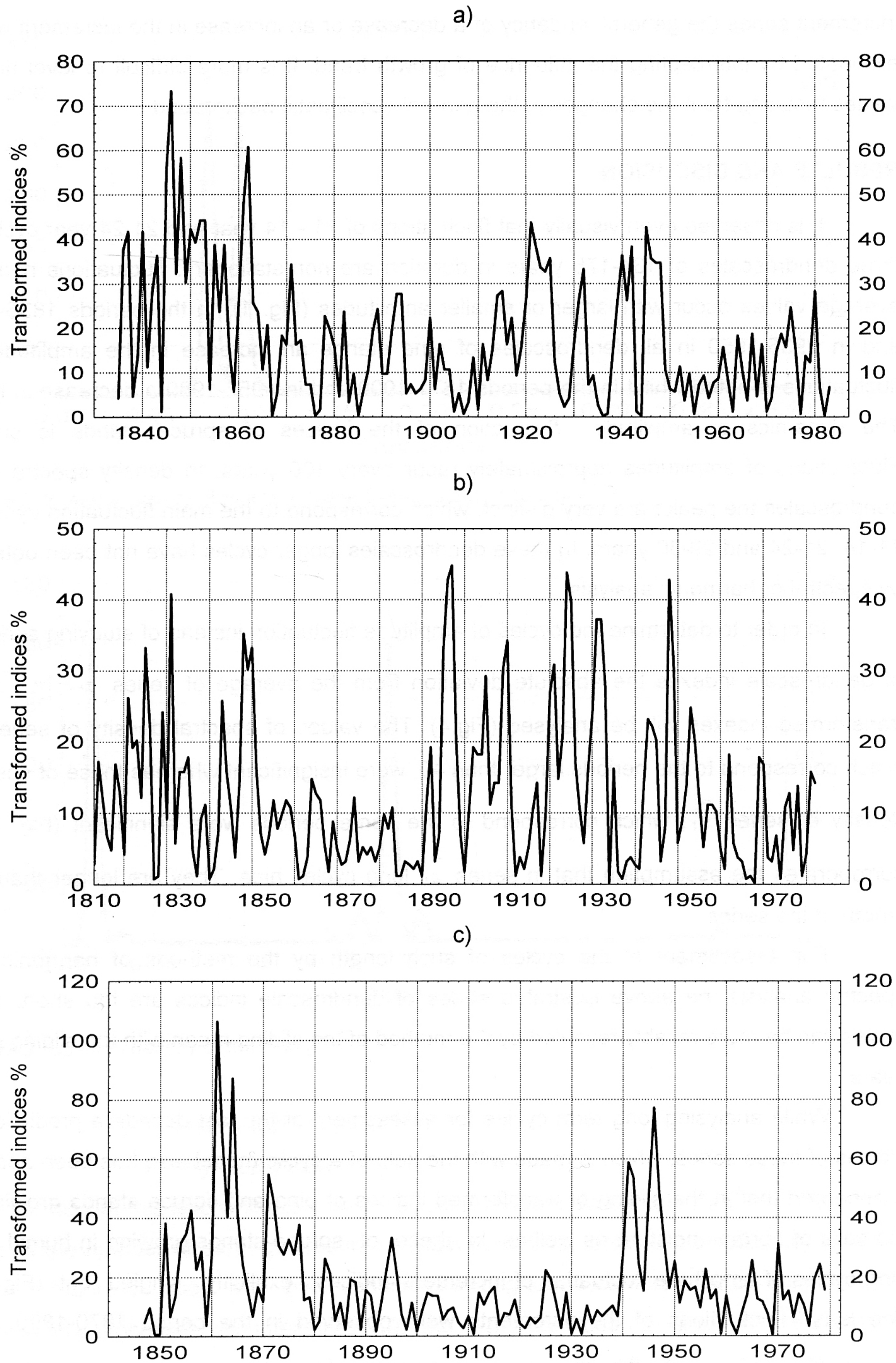

Figure 4. Transformed indices of pine (a), (b) and spruce (c)

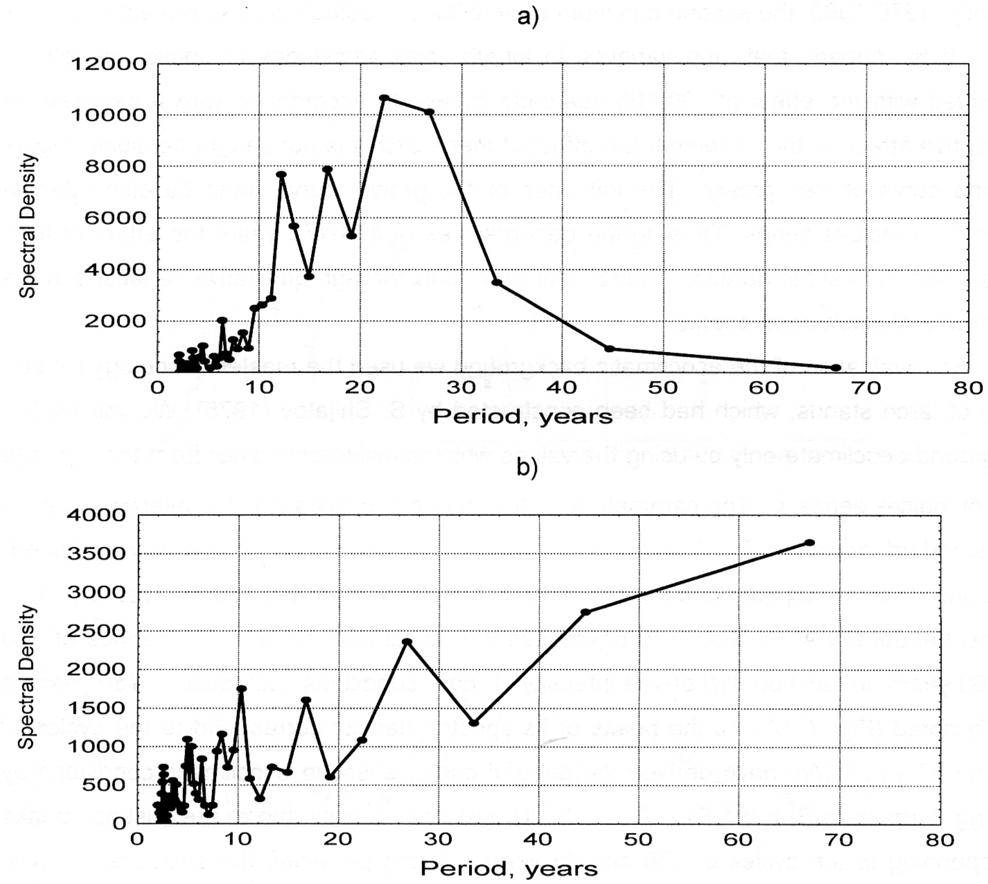

Figure 5. Spectral density of indices z_t (a) and transformed indices $\bar{\bar{z}}_t$ (b) of the standard chronology of spruce stands growing in the soils of surplus moisture

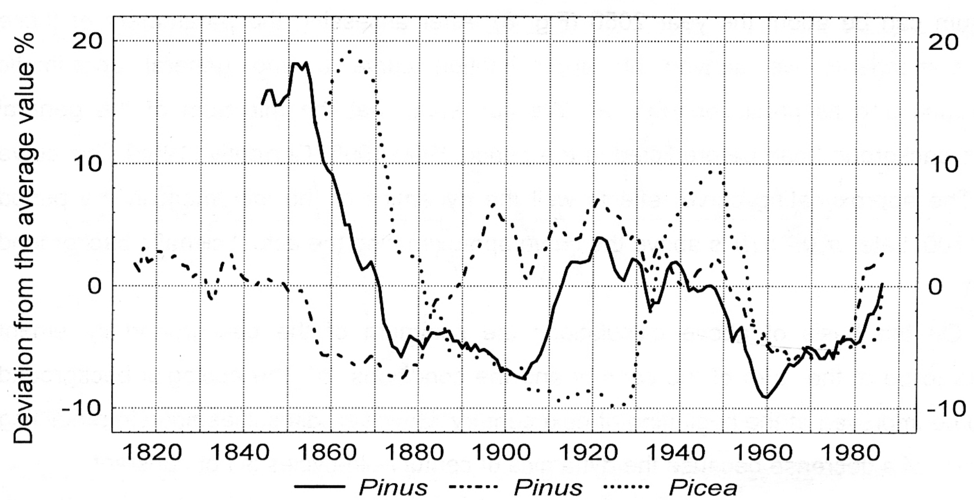

Figure 6. The derivation of the average values of amplitudes fluctuation of transformed indices in the dendroscales of *Picea abies* and *Pinus sylvestris*

Currently, 1970-1980, the second minimum of amplitudes fluctuation of increment indices is noted. It is hoped that the variation in length and amplitudes in above periods is associated with the effect of 90-100 years-old cycles. In accordance with a decrease in quantitative effect in the increment the effect of these cycles is not caught because it "gets into" the curve of tree growth. The influence of the growth curve must be eliminated in constructing indices series. Thus, in the dendroscales of 134-175 years the effect of long cycles (over 90 years in duration) may reveal itself only through qualitative variations in the parameters of cyclic components.

For evaluation of the ecoclimatic background we used the masterchronology (of 867 years) of larch stands, which had been constructed by S. Shijatov (1975). We will assess background ecoclimate only by using the values which considerably differ from the average value of indices series $\bar{x}$. The parameters of this series of indices are: the average value is 100, standard deviation 35. It must be noted that function $n_+(t)$ of intensity of "good" conditions tends to augment and the minima in it are observed every 350-400 years (Fig. 7, a). Spectral density of function $n_+(t)$ possesses the peaks corresponding to periods of 170 and 360 years. In function $n_-(t)$ of the intensity of "bad" conditions fluctuation of 180 years is visually noted (Fig. 7, b) and the peaks of its spectral density correspond to the cycles of 178 and 67 years. We have derived the general curve reflecting ecoclimatic conditions by applying formula $n_+(t)-n_-(t)$ (Fig. 7, c). In its spectral density there are distinct peaks corresponding to the cycles of 178 and 65 years. Having perfected the structure of cyclic components $n_+(t)- n_-(t)$ by the method of harmonic analysis we stated the cycles of 176 (most distinct), 357 and 65 years (Fig. 8). The minimum of the cycle of 176 years will be about the year 2000, the last minimum of a cycle of 357 years was in 1890 and the next maximum can be about the year 2050 (Fig. 8). After assessing the parameters of these cyclic components we derived an approximation curve of the general ecoclimatic background and its prediction (Fig. 9). We can state that the minimum of the general climatic background can be predicted in the period 1990-1995. Currently (1998), this curve rises. The approximating curve reflects well the dynamics of the increment in the period 1300-1700. Later $n_+(t)- n_-(t)$ is above the curve approximating the actual climatic background (Fig. 9).

On the basis of above calculations the minimum of the background increment appears to be at the turn of the century and the conditions of the ecologial background tend to be improved at the beginning of next century. However, difficulties arise in predicting the extent of a decrease because the dynamics of century-old-cycles is not constant.

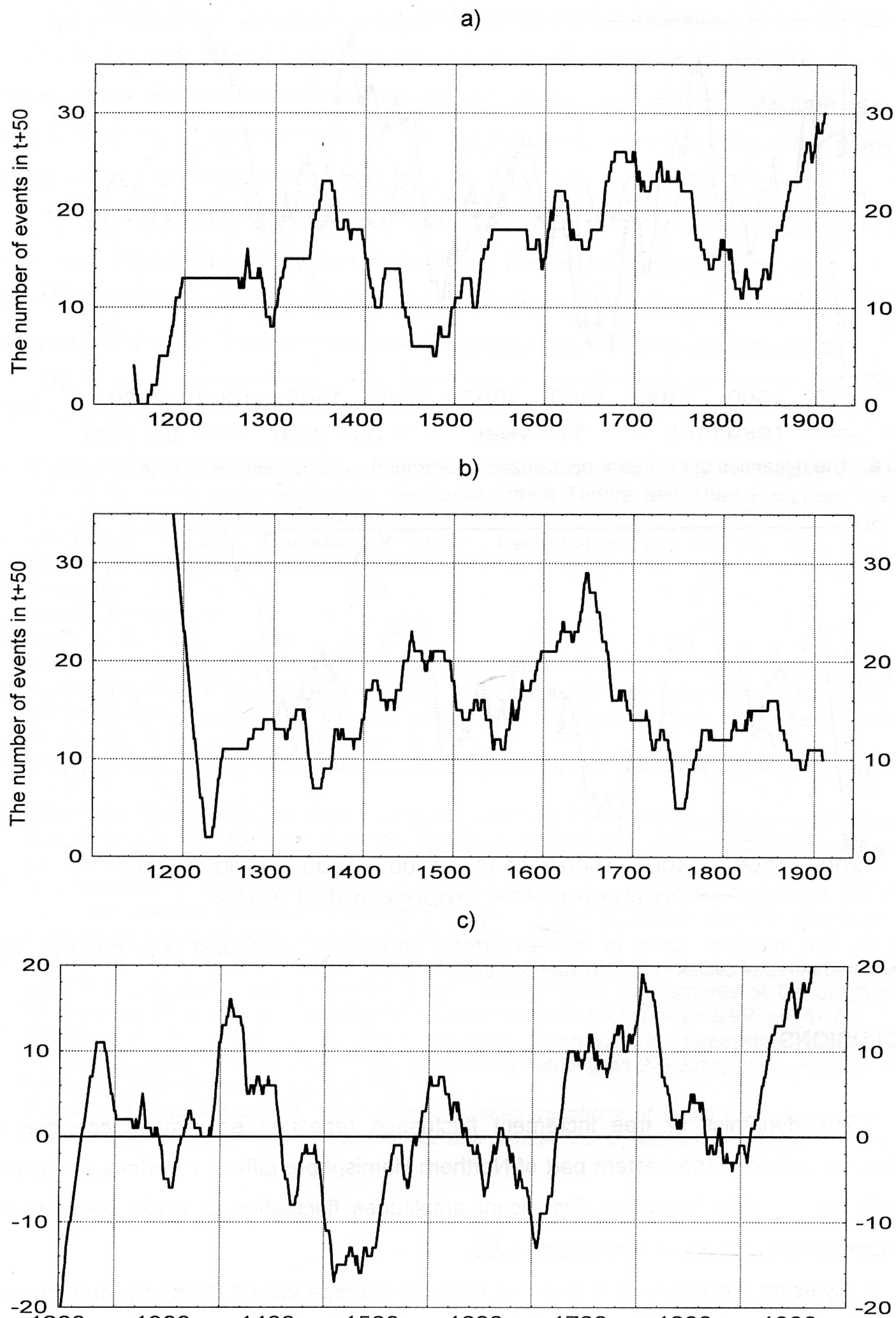

Figure 7. Dynamics $n_{+}(t)$ of "good" conditions for the growth a), dynamics $n_{-}(t)$ of "bad" conditions for the growth b), assesment $n_{+}(t)$ - $n_{-}(t)$ of the ecoclimatic background

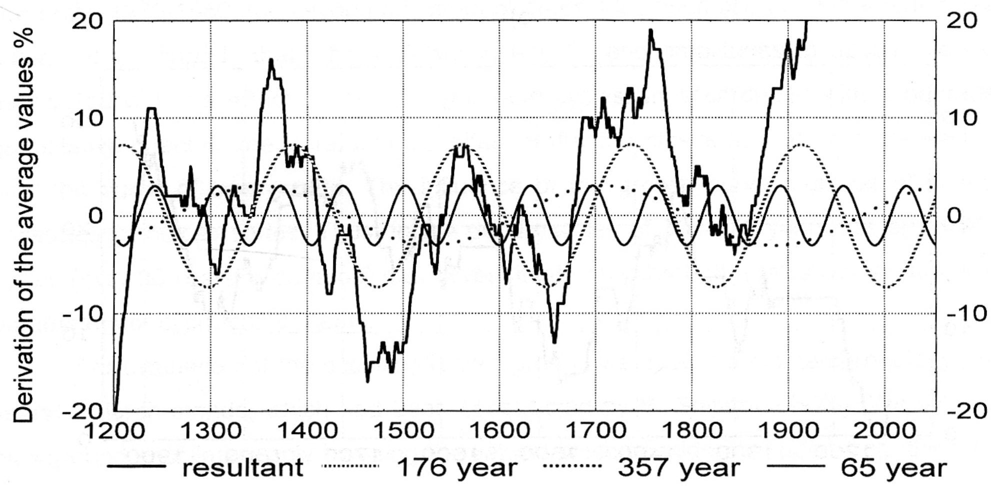

Figure 8. The dynamics of long term ecoclimatic background cyclic fluctuation (122-2050 year)

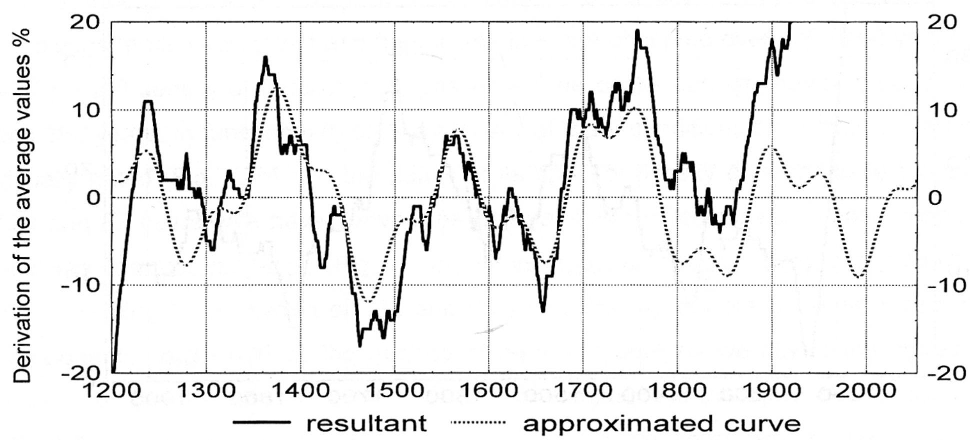

Figure 9. The resultant curve of the ecoclimatic background, calculated with $n_{+}(t)-n_{-}(t)$ and approximated curve of cycles (176, 357 and 65 years)

CONCLUSIONS

1.The dynamics of tree increment fluctuation reflecting ecoclimatic changes in Lithuania as well as in the eastern part of Northern Hemisphere differs in verious periods of time and has a cyclic character. Significant amplitudes fluctuation of cyclic components recur approximately every hundred years (≈90).

2. By using the values of differences from the average values (being beyond interval $\bar{x}+\sigma$) the dynamics of "good" and "bad" conditions of the climatic background for tree growth has been revealed. It is hoped that the number of these seldom occurring events varies according to the Poisson's law.

3. With the aid of approximation of the function of intensities of the Poisson's law which is the sum of cyclic components 176, 356 and 65 years in duration, the resultant curve of the general climatic background was created and growth maximum around the years 1230; 1370; 1560; 1710-1760; as well as growth minimum about the years 1290; 1460; 1670; 1850 and 1990 was stated.

4. On the basis of above calculations the current minimum of the background for tree increment is expected at the turn the century. However, difficulties arise in predicting the extent of a decrease because the dynamics of century-old-cycles is not constant. Thus, the nearest cyclic maximum of the increments can be expected about the year 2020.

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