QUANTITATIVE ANALYSIS OF TREE RING SERIES

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Abstract

Results of autocorrelation, spectral and harmonic analysis of time series of tree rings and different external factors (average monthly temperatures, precipitation, solar activity) and relations between them are presented in the article. Taking into account rather weak correlation between climatic factors and tree growth (width of tree rings), possibilities to transform tree ring series and to exclude autocorrelation process, in order to increase correlation with climatic factors, was investigated. On the basis of obtained results, modification of multidimensional response models was made. Investigation of combined models (climatic factors and autocorrelation function included) has shown, that their predictive capacity is essentially better than predictive capacity of pure response models.

Keywords: Tree-rings series, autocorrelation, spectral , harmonic analysis, response models

INTRODUCTION

For the quantitative assessment of anthropogenical changes of biological indicators and parameters, the problem of norm (normal growth in the case of tree ring analysis) is very important. Taking into account quasiperiodical fluctuations of biological and environmental parameters, detection of anthropogenical signal is a rather sophisticated problem. Particular difficulties arise in the case of low level chronicle environmental pollution of regional scale. Methods and indicators should have a high priority to allow the use of retrospective information for a sufficiently long period. Erroneous conclusions may be obtained with accurate, but short term date.

Radial tree increment (width of annual tree rings) is one of the most perspective indicators for the environmental impact assessment. Despite its not very high sensitivity, the method provides important long-term series information and is very useful for forest monitoring needs (Juknys, 1994).

Assessment of anthropogenic changes of investigated indicators on the background of its natural quasi-periodical fluctuations is one of the main problems of environmental science. Methods based on the quantitative analysis of tree ring-series of injured stands and dependence of the intensity of growth (width of annual rings) from different exogenous factors, are most promising (Cook, 1987; Eckstein,1989). The value of these methods depends on the level of our knowledge in the scope of causes of natural tree ring - series fluctuations.

Climatic conditions (temperature and precipitation) and solar activity usually are considered as a main exogenous factors, resulting fluctuations of the width of annual tree rings (Bitvinskas, 1974; Fritts, 1976; Shiyatov ,1987). Different methods of quantitative analysis of time series and relations between them, as well as possibilities to improve resolving capacity of response models and retrospective prediction of normal tree growth are analyzed in this article.

MATERIALS AND METHODS

Tree ring series from twelve *Scots pine* semimature stands, time series of average monthly temperatures and monthly precipitation as well as time series of solar activity were analyzed.

Primary investigation of tree ring series including possible cyclic components was made on the basis of autocorrelation analysis. For quantitative assessment of cyclic components, are typical for different processes, spectral density analysis (Bendat, Piersol, 1980) technique was used. Taking into account, that spectral analysis provides only rough assessment of main cyclic components, harmonic analysis (Anderson, 1974) is used for more detail their description and presentation.

Two-dimensional spectral analysis technique (functions of coherency) was used to make more deep analysis and to check relations between two time series in different frequency diapasons (Bendat, Piersol, 1980).

Correlation between tree ring series and external factors (temperature, precipitation, solar activity), as a basis for response models, was analyzed.

Taking into account rather weak correlation between climatic factors and tree growth (increment), possibilities to transform tree-ring series and to exclude autocorrelation process in order to increase correlation with climatic factors, was investigated. On the basis of obtained positive results, modification response models was made in order to increase their predictive capacity.

Climatic response models are rather common technique to predict "normal" growth (increment) of damaged stands (Cook, 1987; Juknys,1994).

Two types of such models were investigated and compared:

- only climatic factors included into response function model;
- climatic factors and autocorrelation functions included into response function model.

RESULTS

Examples of tree ring indices, average monthly temperatures and solar activity time series are presented in figure 1. Already from the first view, rather different patterns of fluctuations for those different indicators can be recognized.

Mostly regular fluctuations with well known 11 years cycle are characteristic for solar activity and mostly complicated pattern of fluctuations is characteristic for biological indicator - tree ring width.

Quantitative analysis, of those three types of fluctuations and relations between them is presented further.

Examples of autocorrelation functions of those indicators are presented in Figure 2. For tree ring series strong correlation with past year radial increment (r=0,5-0,8) is characteristic and the correlation function has pattern of damped oscillations with increase of lag. Statistically significant correlation usually can be noticed only with increment of 2-3 former years, and sometimes negative correlation with increment of former 6-7 years. In 10 years lag autocorrelation usually approximates zero values.

Completely different pattern of autocorrelation function is typical for climatic indicators - average monthly temperatures and monthly precipitation.

As it seen from figure 2, correlation of current year March temperatures with that of former years is very weak and usually statistically insignificant (p=0,95). Really there is no autocorelation in time series of climatic indicators.

Autocorrelation function for solar activity has very strongly expressed sinusoid pattern. As it can be seen from figure 2, 11 years cyclic component can be detected already from autocorrelation function of solar activity.

For quantitative assessment of quasiperiodical components, spectral analysis of investigated time series was performed. As it can be seen from figure 3, for tree ring series middle-term: 9-15 and 20-25 years cyclic components usually are most powerful and usually takes about two thirds of general dispersion. Similar results were obtained by other authors (Kairiukstis, Dubinskaite,1987; Shiyatow,1987; Stravinskiene, Vencloviene, 1998).

Cyclic components for time-series of climatic factors usually are rather weak and short term (2-7) years cycles are prevailing (Fig.3). As it seen from figure3, function of spectral density for solar activity has one very strong 11 years length cycle.

More detail description and presentation of cyclic components was made on the basis of harmonic analysis. For investigated tree ring-series 2-5 statistically significant cyclic components usually were separated. As it seen from figure 4., three main 12, 16 and 29 years length cycles were detected during harmonic analysis of presented tree ring-serie.

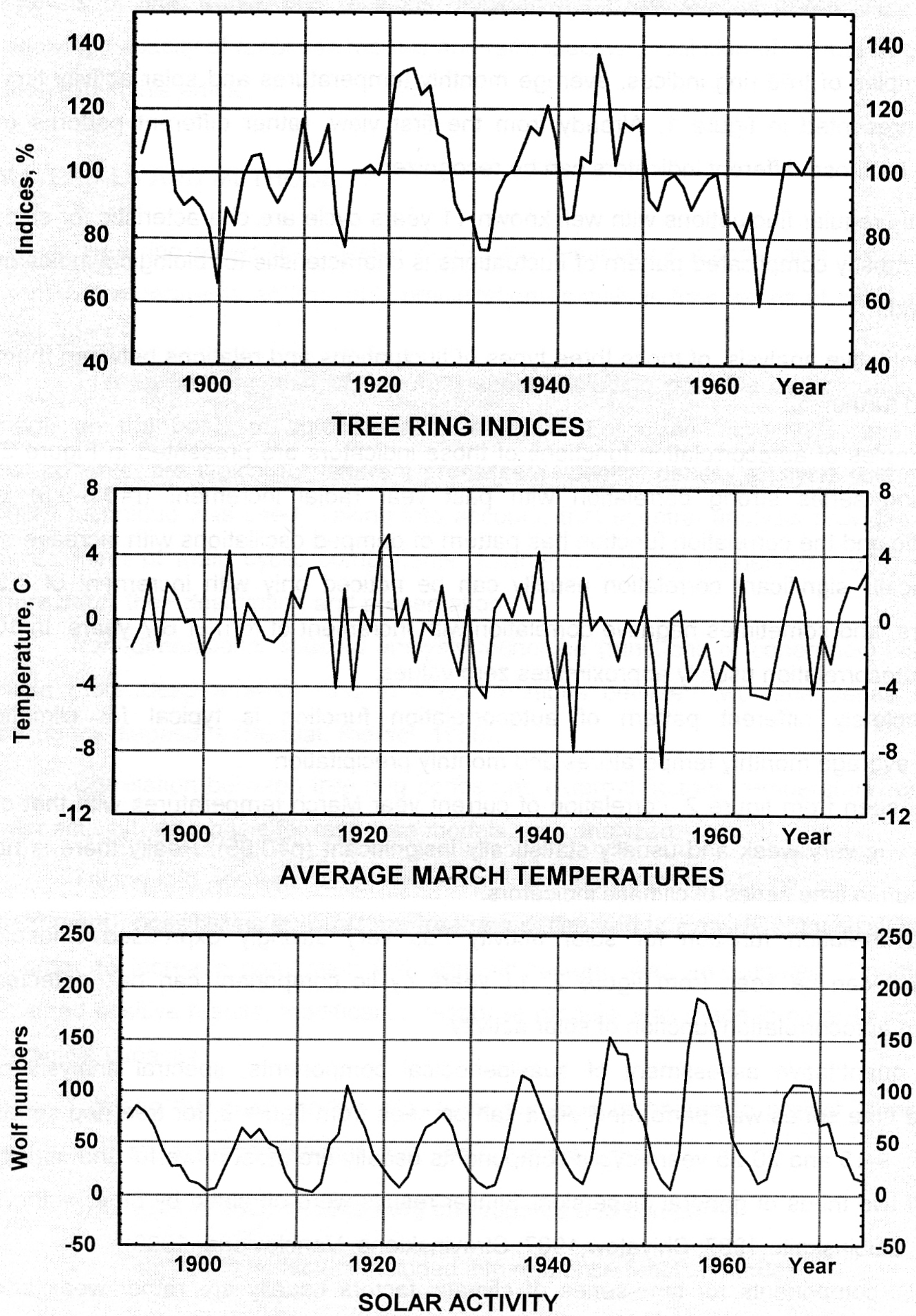


Figure 1. Time series of different environmental indicators

Resultant of those tree cycles is shoved below. As it seen, it represents quite well main fluctuations of tree ring indices.

For average March temperature one rather weak 8 years length cycle, and for solar activity - well known very strong 11 years length cycle was separated.

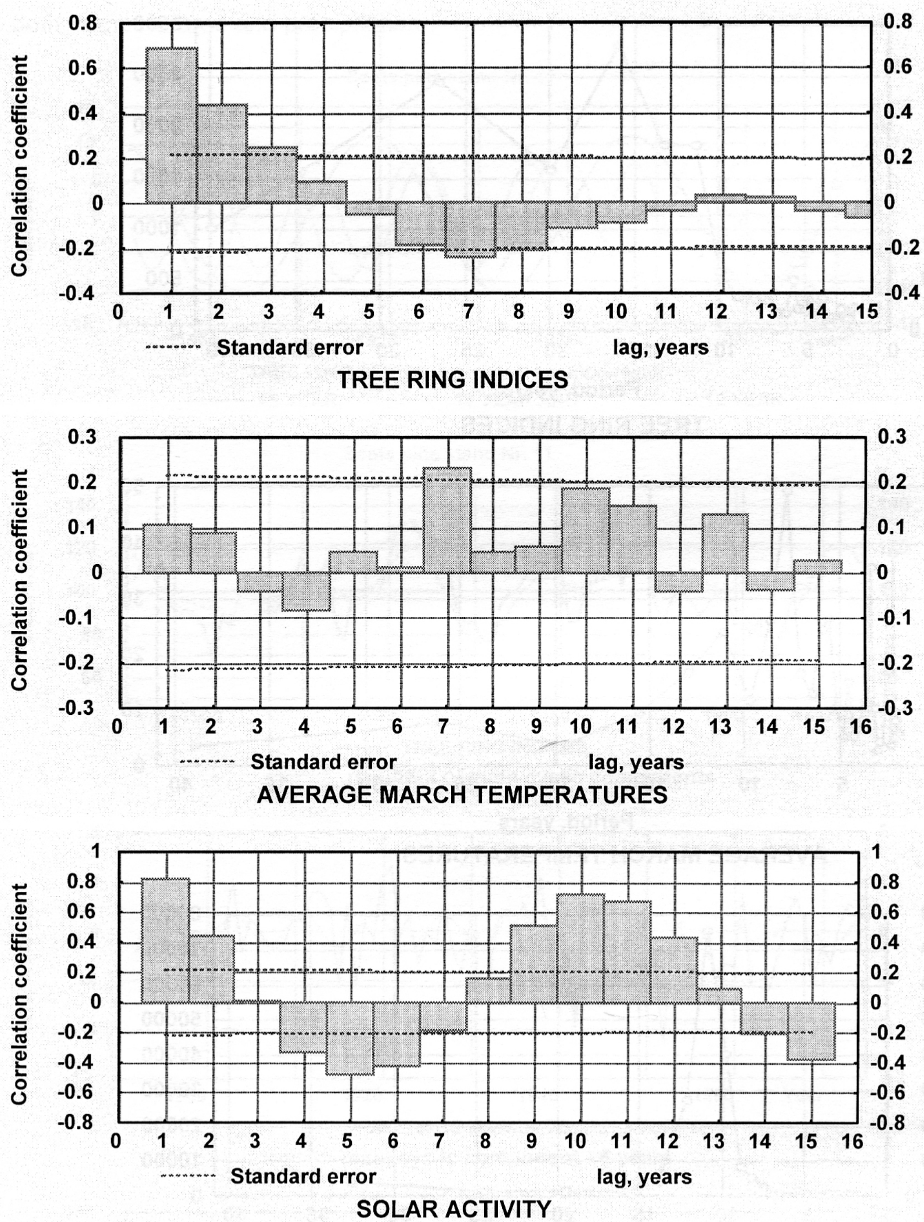


Figure 2. Autocorrelation function

Analysis of impact of different natural external factors shows, that the temperatures of late winter (February), early spring (March, April), and temperatures of late summer (August) most strongly affect the growth of Scots pine in Lithuania. For some cases the temperatures of autumn months of the past years (September, October) have an essential impact on the tree increment.

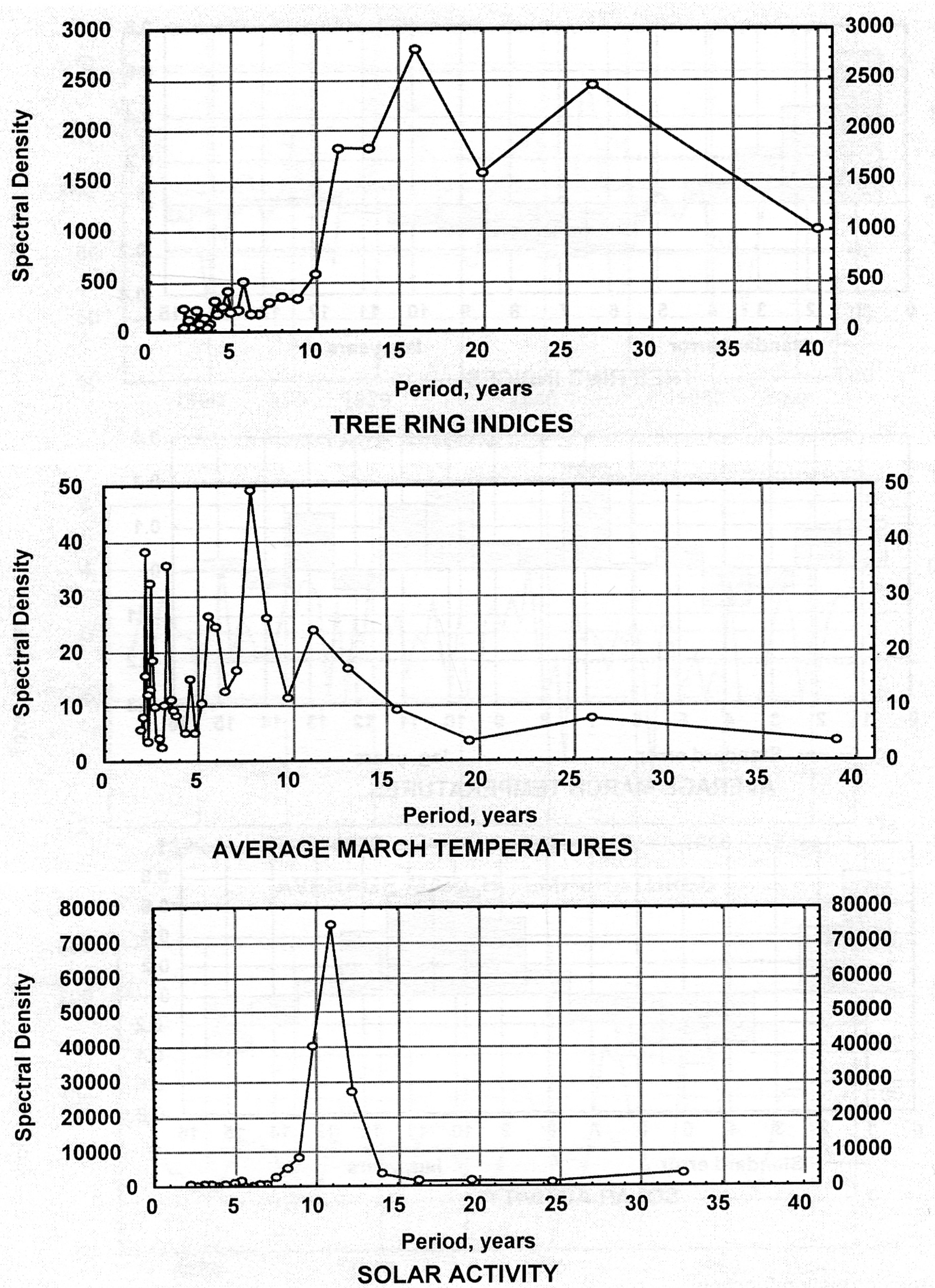


Figure 3. Functions of spectral density

The impact of precipitation is less essential than the impact of temperatures in our latitudes. The closest relations were found between annual tree increment and precipitation of late winter (February) and summer (June and July). As it seen from figure 5, impact of climatic conditions of late winter and early spring in most cases are statistically significant for both, temperatures and precipitation.

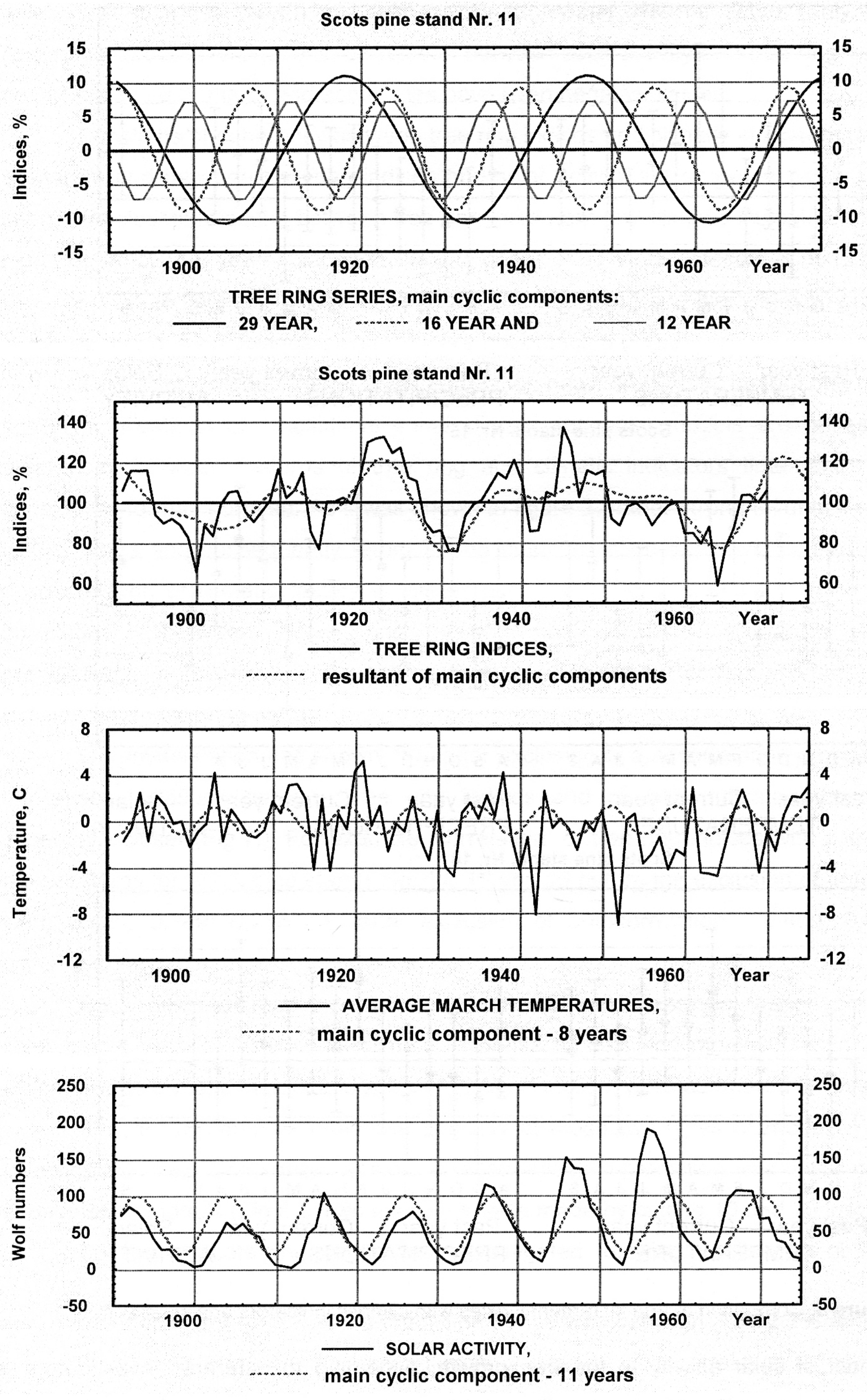


Figure 4. Main cyclic components of different environmental indicators

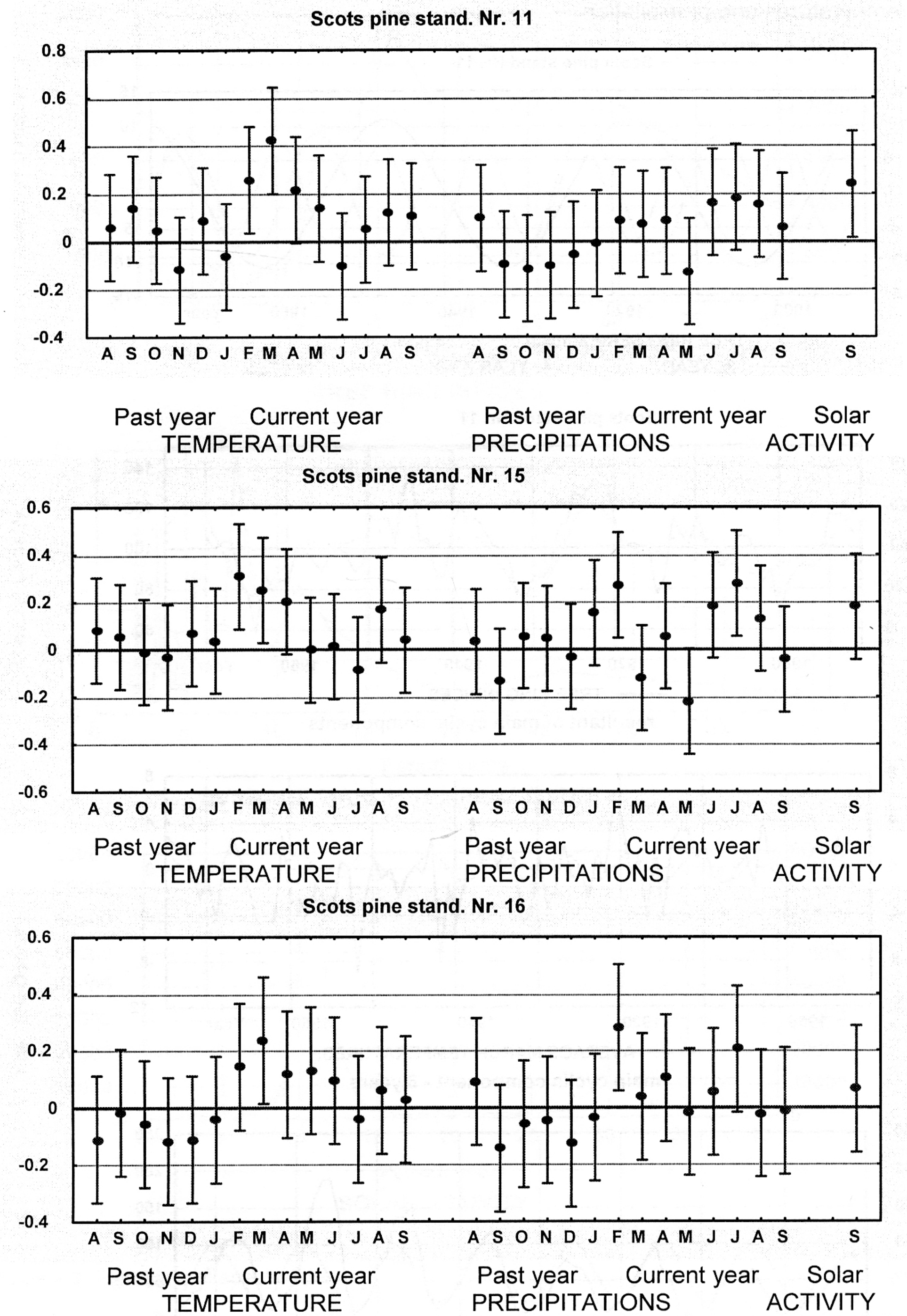


Figure 5. Correlation of tree increment indices with climatic indicators and solar activity

Impact of solar activity to the tree growth, according to different investigators is rather different in different regions. For middle latitudes no more significant relations between solar activity and tree rings width usually are not detected, and sometimes even correlation sign for the same tree ring series may be changed. Main idea is, that solar activity influence tree growth only indirectly, through other external factors (Shiyatow, 1987). According to our investigations, correlation between solar activity and tree ring width usually do not exceed 0,2 (Fig.5) and sometimes have even negative values.

Functions of coherency between tree ring indices and climatic indicators (temperature of March) and between tree ring indices and solar activity are shown in figure 6. It can be seen, that closest relations between tree ring increment and climatic indicators take place in high frequency (4-6 years) diapason. Next to peaks usually are detected in middle frequency (9-12 and 22-28 years) diapasons. Coherency between tree ring indices and solar activity is much weaker and no obvious extremes were not detected (Fig.6).

Taking into account rather weak correlation between climatic factors and tree growth, some modifications of multidimensional climatic response models are necessary. Main differences between patterns of tree ring and climatic indicators time-series should be considered for this purpose. As it was shown in figure 2, rather strong influence of growth of former years and consequently rather strong autocorrelation is typical for tree ring series. Autocorelation of climatic factors is almost absent. The idea is, that in order to increase correlation between tree ring width and climatic indicators (temperature, precipitation), autocorrelation process (influence of increment of former years) should be excluded from tree ring series.

Our investigation has shown, that after exclusion of autocorrelation process from tree ring-series, relations between tree ring indices and climatic indicators became rather essentially closer (Fig.7.). For example, correlation of tree ring indices with average March temperatures for Scots pine stands No. 11, 15 and 16 before the exclusion of autocorrelation were 0,421; 0,249; 0,236 and after exclusion of autocorrelation - 0,459; 0,407; 0,410 consequently.

Possibilities to improve predictive capacity of multidimensional response models, was investigated further. Traditional climate response models and modified response models, which include climatic factors and autocorrelation function, were compared for this purpose.

In order to compare predictive capacity of those two types of models, the end of investigated tree ring-series was cut and retrospective prediction was made on the basis of developed models (Fig.8.). Two exercises were made by cutting 10 and 20 last years.

For twelve Scots pine stands, were investigated, folowing results were obtained:

- standard error for ten years prediction period was between 7,5-12,7% for first type of models and 6,5-9,4% for second type of models (autocorrelation function included additionally);

standard error for twenty years prediction period was between 11,1-16,0% for first type of models and 7,8-13,8% for second type of models.

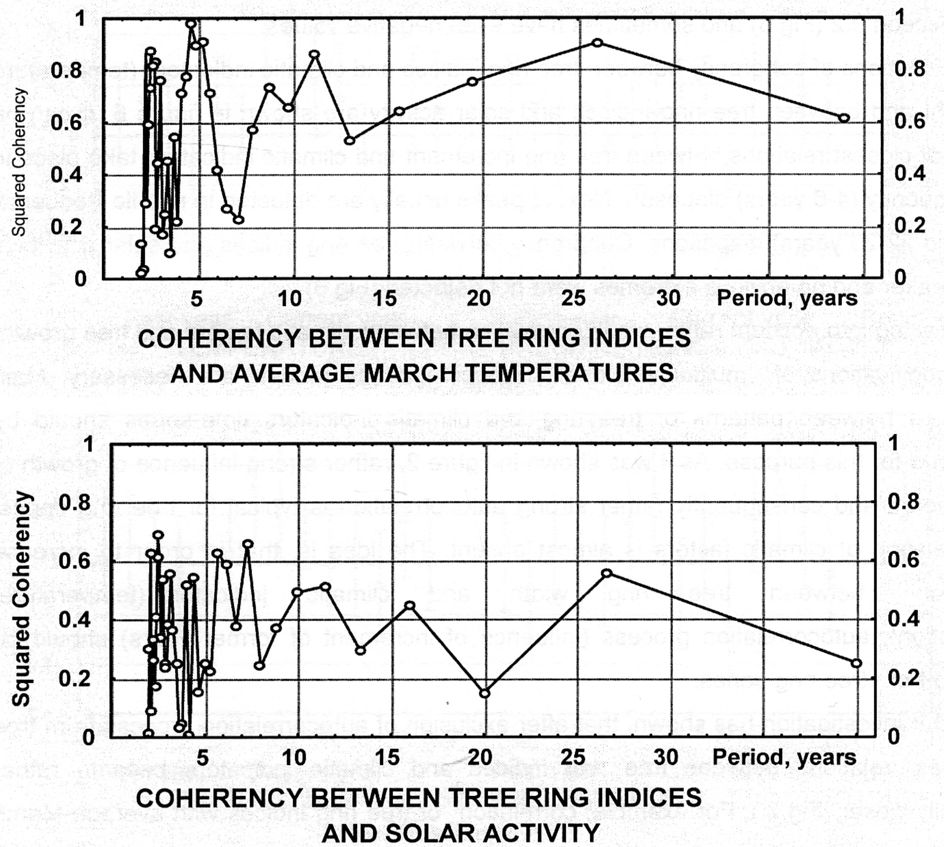


Figure 6. Functions of coherency

As it can be seen, rather essential decrease of standard errors and rather essential increase of resolving capacity consequently, was achieved by including autocorrelation function to the response model. Better prediction of normal tree growth and more accurate assessment of anthropogenical changes of tree increment can be made an the basis of such kind of models.

CONCLUSIONS

1.Temporal fluctuations of tree ring series and time series of external factors (climatic parameters, solar activity) have different pattern. Most complicated pattern of temporal fluctuations is characteristic for biolgical indicator - tree increment and most regular fluctuations are typical for solar activity.

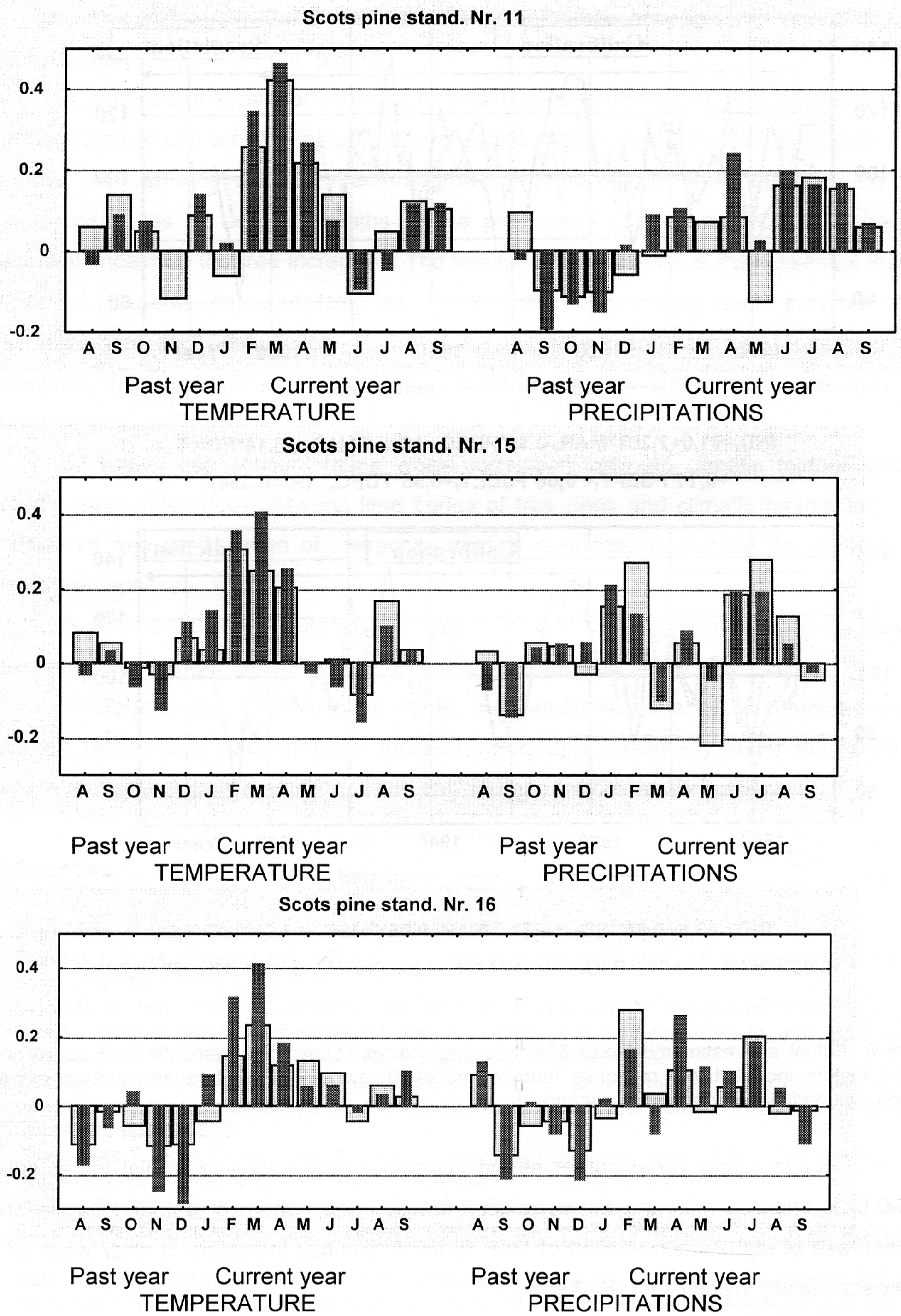
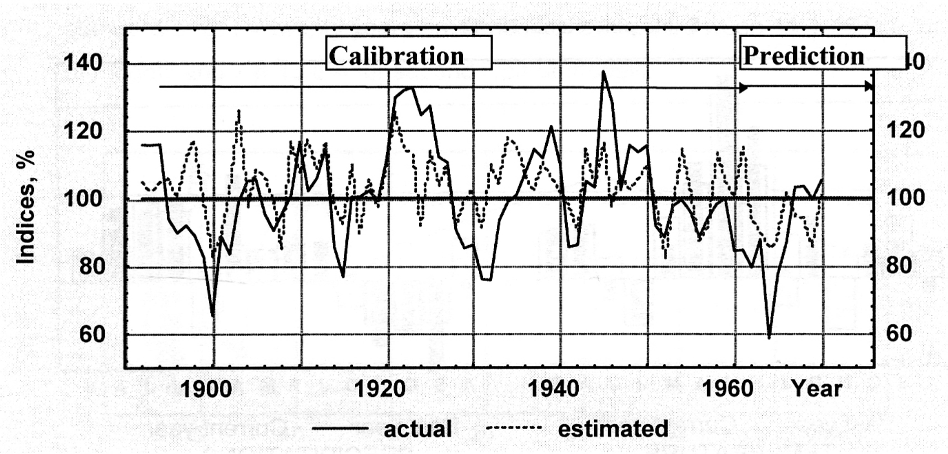
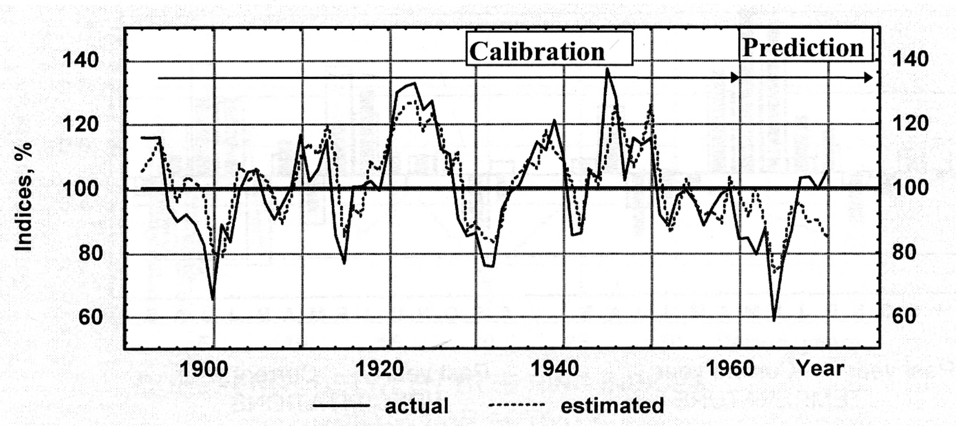


Figure 7. Correlation of tree increment indices with climatic indicators before (bright) and after excluding of autoregression process (black)



$$IND_t=91,0+2,26T*MAR_t-0.18*PDEC_{t-1}+0,1*PAUG_{t-1}-0,14*POKT_{t-1}$$
$$+0,11*PSEPT_t+0,06*PJULY_t+0,95*TDEC_{t-1}\ (R^2=0,354);$$



$$IND_t=43,6+0,68*IND_{t-1}+1,57*TMAR_t-0.08*PDEC_{t-1}+1,09*TAPR_{t-1}$$
$$-0,09*PMAR_{t-1}+0,037*PJUL_t+0,1*TAPR_t-0,06*PNOV_{t-1}-0,94*TJUN_t\ (R^2=0,645);$$

Figure 8. Actual and estimated *Scots pine* tree ring indices (*Scots pine* stand Nr. 11) above-only climatic factors included into response function model. Below climatic factors and autocorrelation function included into response function model

2. For tree ring series rather strong correlation with past year radial increment (r=0,5-0,8) is characteristic and the correlation function has pattern of damped oscillations with increase of lag. Autocorrelation of time series of climatic indicators is wery weak and usually statistically insignificant (P=0.95).

3. Results of spectral analysis showed, that for tree ring series middle term 9-15 and 20-25 years quasiperiodical coponents are most powerfull and usually takes about two thirds of general dispersion.Cyclic components of climatic factors are rather weak and short term

(2-7 years) quasiperiods are prevailing. Solar acrivity has one powerful and well known approximately 11 years lenght period.

4. Analysis of impact of different external factors to tree growth has showen, that the temperatures of late winter (February), early spring (March, April), and temperatures of late summer (August) most strongly affect the growth of Scots pine in Lithuania. For some cases the temperatures of autumn months of the past years (September, October) have an essential impact on the tree increment. The impact of precipitation is less essential than the impact of temperatures in our latitudes. The closest relations were found between annual tree increment and precipitation of late winter (February) and summer (June and July). Relations of tree growth with solar activity is rather weak in our latitudes and, as a rule, statistically insignificant.

5. Taking into account rather weak correlation between climatic factors and tree growth, main differences between time series of tree rings and climatic factors should be considered and modification of response models is necessary in order to increase their predictive capacity.

6. After exclusion of autocorrelation process from tree ring series, relations between tree ring series and climatic factors become rather essentially closer.

7. General conclusion can be made, that predictive capacity of combined models (climatic factors and autocorrelation function included) is essentially better than predictive capacity of pure response function, when only climatic factors are included.

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