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# Growth variability of Scotch Pine in Kaunas region of Lithuania and an approach Towards its long term predictability

## 1. Introduction

The scotch pine (*Pinus sylvestris* L.) is a boreotemperate species growing in diverse ecological habitats. Its wide geographical distribution provides a special status to it on view point of forestry. Though various authors have contributed to the tree-ring study of scotch pine, significant contribution to its growth variability in different geographical regions have been made by STUPNEVA and BITVINSKAS (1978) and BUDRIUNAS and BITVINSKAS (1987). While working on the variability of radial increment of scotch pine on various points of its natural habitat along the Murmansk-Carpathians profile BUDRIUNAS and BITVINSKAS (1987) noted that the annual increment noticeably decreases from south to north. In south where the climate is more suitable, the growth is vigrous and maturity of the forests comes earlier. In north, with the increasing climatic severity the growth slows down and aging is less noticeable and longer.

Prediction of any time series is principally based on the presence of determined components in it. The intraseries regularities could be used successfully for prediction if the long term series is available. The dendrochronological series provides an advantage over the others in terms of its length. The series provides the long term annual and even intra-annual (seasonal) information about the growth variability of trees. Dendrochronological time series analysis by various workers (LAMARCHE and FRITTS 1972; STUPNEVA and BITVINSKAS 1978; BERRY et al. 1979; MITCHELL et al. 1979 and others) have shown that the fluctuations in tree ring indices differing in amplitude and duration are repeated more or less regularly over time. With growing understanding of the dendrochronological series, cyclic components present in the series have been used by several workers (BERRY et al. 1979; KAIRIUKSTIS 1981; KAIRIUKSTIS and DUBINSKAITE 1987, 1989; SHIYATOV and MAZEPA 1987; MAZEPA 1989) for prediction of the series. The prediction of dendrochronological series provides an idea about the long term availability of timber resources and therefore, could be very useful in judicious development of forest resource management policies.

Growth periodicity of scotch pine in Lithuania as studied by BITVINSKAS (1984) shows 20–22 year cycles in peat bogs and approximately 11 year cycle in its optimal growing sites. According to him the cyclic regularities of the radial increment differ among plant populations of the same species growing in remote regions of geographical latitudes. In present study the spectral analysis has been used to screen the most important cyclic components present in the dendrochronological series of scotch pine from Kaunas in Lithuania and its applicability in long term prediction of the series has been discussed.





## 2. Study area

The study area lies in the south-eastern part of the town Kaunas in Lithuania (54°55′ N and 23°50′ E). The proximity of the Baltic Sea has a mitigating effect on seasonal temperature fluctuation. Average monthly temperature for the period from 1840–1970 as given in figure 1 shows that January is the coldest month and July the hottest. The average July temperature reaches upto 16–17 °C. In summer average monthly temperature fluctuations are lass as compared to in winter. On average about 180 days are without freezing temperature. The average annual precipitation is about 640 mm. Monthly distribution of precipitation for the period from 1893–1972 indicates that maximum rainfall occurs in June and July (Fig. 2).

The forest from where the samples were collected for the present study is growing on sandy-loam podzolic soil in the old valley of river Nemunas which was formed in Late Glacial Period. The soil is acidic and highly prone to leaching. As the water percolation in the soil is very high even a small period

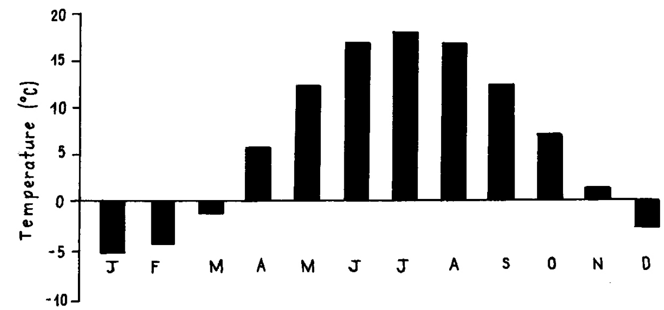


Fig. 1: Average monthly temperature for the period from 1840–1970

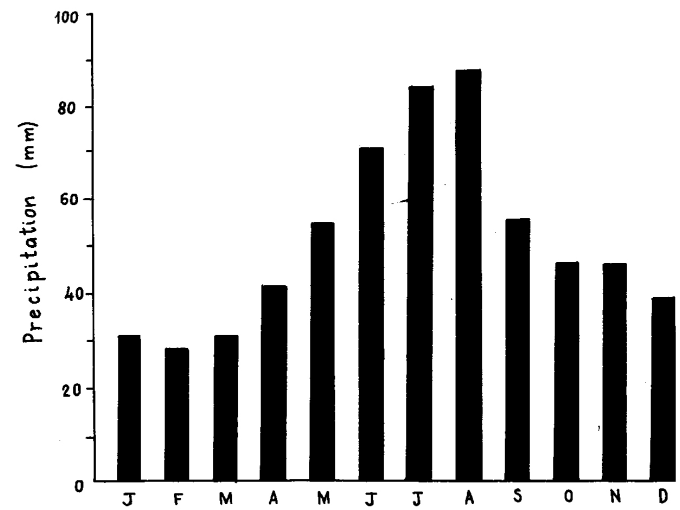


Fig. 2: Average monthly precipitation for the period from 1893–1972

without precipitation greatly effects the tree growth as the upper part of the soil virtually becomes dry. In the area on dry elevated soils pure thickets of pine are growing whereas on damp soils pine is found growing mixed with spruce. Trees from which the samples were collected are growing on elevated places at about 300 m from the left bank of the river Nemunas where pine reaches upto the height of 27 m with an average diameter of 42 cm.

## 3. Chronology preparation and its characteristics

Tree cores on which the present study is based were collected by one of the authors (JK) in the summer of 1979 and again supplemented by fresh collection made in summer of 1990. As trees were straight with very good circuit symmetry usually one core was taken from each tree at the breast height. For dating of the growth rings, pointer year method as practised in the laboratory of dendroclimatochronology, Kaunas, Lithuania was used. Missing rings were located in many of the samples and following the standard dendrochronological procedures they were assigned width of zero in measurement values. Dated annual rings were measured with the accuracy of 0.01 mm and converted into dimensionless ring width indices following the procedure of BITVINSKAS (1974). As the standardization practised in dendrochronology removes the variance within a particular frequency band or zone from a tree ring series, the smoothing length should be decided according to the objective of the study. For present chronology ring width measurements of individual trees was standardized with the smoothing length of five years. The chronology extending from 1795 – 1989 AD shows high year to year fluctuation (Fig. 3). Climate growth relationship study has shown that the

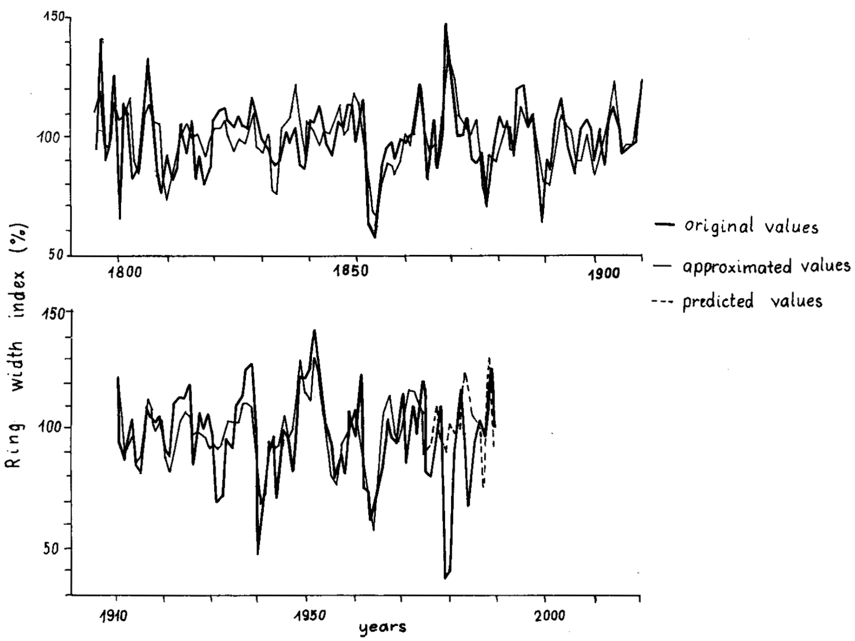


Fig. 3 Scotch pine chronology along with approximated and predicted values



growth of scotch pine is susceptible to the fluctuation in temperature of previous years' December, current years February, April and August whereas the rainfall of current years April and July are very important for tree growth in the area. Detailed information about the dependence of radial increment of scotch pine on temperature and precipitation has been given by KARPAVICHUS (1978, 1984).

Authors one of the main objective was to get the dendrochronological series with minimum of anthropogenic influence for prediction purposes. To check the effect of anthropogenic factors on tree growth, if any, the present chronology was compared with the chronology prepared from another area which is situated about 60 km away from the town Kaunas and has negligible biotic pressure. The soil conditions of this area are similar to that of the former. On comparison it was found that both the chronologies showed almost similar growth pattern without any sign of growth decline.

## 4. Long-term prediction of the scotch pine series

The identification of well expressed cycles in the series that are stable in time makes the sound basis of prediction. The prediction is based on the principle to find the prominent cycles in the series which involves identification, approximation and extrapolation of the most important cyclic components. To carry out the analysis soft ware package was developed and well tested with artificial series of known cyclicity. The essentials of the steps could be given as below.

The generalized and centralized dendrochronological series $z(k)$ was approximated by the sum of harmonical components which could be expressed as

$$z(k) \stackrel{\cdot}{\sim} \sum_{i=1}^{\infty} A_i \cos(2\pi f_i k) + B_i \sin(2\pi f_i k) \qquad (1)$$

where $k = 1$ to $N$ years (the length of series)
$\stackrel{\cdot}{\sim}$ is the sign of approximation
$f_i$ is the frequency of harmonical components
$A_i$ and $B_i$ are unknown parameters

For the prediction of series $z(k)$ the unknown parameters $A_i$, $B_i$ and frequency $f_i$ are to be found out. To determine the most important harmonical components with which the approximation is done by means of variance, the sample spectrum was used. The sample spectrum shows the distribution of $z(k)$ variance by the harmonical components according to their frequencies. The spectrum of the index series was calculated by using the formula

$$R_{zz}(l) = 2\left[1 + 2\sum_{k=1}^{L-1} R_{zz}(k)\, w(k) \cos\frac{\pi l k}{F}\right] \qquad (2)$$

where $l = 0, 1, 2, \ldots F$
$F = (2L$ where $L$ is the length of correlation function)
$k = 1$ to $N$ (where $N$ is the length of the series)
$w(k)$ is the spectrum smoothing window

the maximum value of $R_{zz}(l)$ is calculated and the argument which agree this value is designed as $l^*$ that is

$$R(l^*) = \max R(l) \qquad (3)$$

where $l = 0, 1, 2, \ldots F$

The fequency which agree this value would be equal to

$$f_i^* = \frac{l^*}{2F} \quad (4)$$

Now the series was approximated by using the formula

$$A_1 \cos(2\pi f_1^* k) + B_1 \sin(2\pi f_1^* k) \quad (5)$$

$A_1$ and $B_1$ values are obtained by means of least square method by minimizing the sum of the squares of the differences of original approximated values which could be expressed as

$$\sum_{k=1}^{N} [z(k) - A_1 \cos(2\pi f_1^* k) - B_1 \sin(2\pi f_1^* k)]^2 . \quad (6)$$

As the evaluation of $f_i^*$ from the sample spectrum which is discrete value may have some error, we used the non-linear regression model

$$A_1 \cos(2\pi f_1 k) + B_1 \sin(2\pi f_1 k) \quad (7)$$

and it was found to be more suitable for the approximation of the series. For evaluation of $A_1$, $B_1$, $f_1$ parameters MARQUARDT (1963) method was used in which the initial values for $A_1$, $B_1$, $f_1$ may be used as 0, 0, $f_1^*$ respectively. When these values are obtained the harmonic components are singled out from the series and new series is obtained which could be expressed as

$$z_1(k) = z(k) - \hat{A}_1 \cos(2\pi \hat{f}_1^* k) - \hat{B}_1 \sin(2\pi \hat{f}_1^* k) \quad (8)$$

In the next step which is identical to the first but differs in the sense that in place of series $z(k)$, $z_1(k)$ is used. After every step the harmonic components are singled out. The sum of the harmonical components which approximates the actual series $z(k)$ could be expressed by the formula

$$z(k) \sim \sum_{i=1}^{I} \hat{A}_i \cos(2\pi \hat{f}_i^* k) + \hat{B}_i \sin(2\pi \hat{f}_i^* k) \quad (9)$$

where $i$ represents the number of steps of harmonic components varying from 1 to $I$.
The synchronization between actual and approximated series specified as synchronization coefficient is calculated and when from step to step difference in synchronization coefficients becomes very small, the procedure of singling out the hormonical components is completed and at the end absolute approximation of the original series is obtained.
The cross-correlation between original and harmonized series was found to be 0.732. The high level of cross-correlation coefficient indicates that the developed model could be used for the prediction of the series. The prediction, $z_2(k)$ could be made by using this model by increasing the years $k$ from $N + 1$ to $N + M$ by using the formula (9) and could be expressed as

$$z_2(k) = \sum_{i=1}^{I} \hat{A}_i \cos(2\pi \hat{f}_i^* k) + \hat{B}_i \sin(2\pi \hat{f}_i^* k) . \quad (10)$$

In order to verify predicted values the approximation was done without the last 15 years of the dendrochronological series and predicted values were compared with the actual data of the series. The coefficient of synchronization between predicted and actual data as calculated according to the procedure of BITVINSKAS (1974) was found to be 68% (Fig. 3).



## 5. Conclusion

The study shows that the presence of cyclical components in the dendrochronological series could be successfully used for the prediction of radial increment of trees for long periods. As the growth periodicity greatly concerns to the national resource requirement, this long term information about the availability of natural resource would be very useful in evaluating the long term future sustainability of the biospheric system. Forestry practices could be accordingly oriented taking into consideration the future growth trend.
The mathematical model suggested for the prediction of dendrochronological series has certain inherent limitations as the approach is based on the assumption of the stationary nature of the series, however, in nature there is no purely stationary process. The level of accuracy in prediction could be improved by judicious selection of series. As the dendrochronological fluctuations are closely tied with the changes in the environmental factors, the dendrochronological series from the areas where some of the climatic factors are limiting the tree growth would be more suitable for such studies.
Another complication in dendrochronological prediction arises due to the increasing influence of anthropogenic factors on tree growth. Due to increasing pollution load, it is found that the climatic response of trees also changes (COOK et al. 1987). In such cases it would be imperative to understand the productivity losses caused due to the pollution and for this the climate response model as suggested by COOK (1987) would be a promising tool.

## Summary

The present study indicates that the cyclic components present in the dendrochronological series could be used for long term prediction of the series. 68% of the coefficient of synchronization between the actual and predicted data indicates considerable level of accuracy in prediction. Such studies seem to have wide potential in understanding the long term availability of timber resources. It is suggested that for prediction studies the dendrochronological series derived from the areas where some of the climatic factors are limitimg the tree growth and anthropogenic influences are minimum should be used.

## Zusammenfassung

Wachstumvariabilität der Waldkiefer (*Pinus sylvestris* L.) in der Region Kaunas in Litauen

Die vorliegende Untersuchung zeigt auf, daß die zyklischen Komponenten, die in dendrochronologischen Serien vorhanden sind, für Langzeitprognosen verwendet werden können. 68% des Koeffizienten der Synchronisation zwischen aktuellen und vorhergesagten Werten zeigen ein beträchtliches Maß an Genauigkeit in der Prognose.
Derartige Untersuchungen scheinen ein großes Potential zum Verständnis der Langzeit-Verfügbarkeit von Holzressouren zu haben.
Es wird vorgeschlagen, für Voraussagen Untersuchungen der dendrochronologischen Serien zu verwenden, die aus Gebieten stammen, in denen einige der klimatischen Faktoren das Wachstum begrenzen und anthropogene Einflüsse im Minimum sind.

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