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THE DEPENDENCE OF ANNUAL RING INDICES ON SOME CLIMATIC FACTORS

VUOSILUSTOINDEKSIEN RIIPPUVUUS ILMASTOTEKIJÖISTÄ

Helena Henttonen

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Seloste

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Tutkimuksessa tarkastellaan ilmastotekijöiden vaikutusta kuusen ja männyn paikallisiin vuosilustoindekseihin lähinnä Etelä-Suomessa. Käytetyt vuosilustoindeksisarjat on saatu aikaisemmista tutkimuksista. Ilmastotunnuksista kuukausien keskilämpötilat ja sademäärät tasoitettiin ympäristön säähavaintoasemien mittaustiedoista. Kuukausien keskilämpötilojen perusteella laskettiin lisäksi lämpösummia eri ajanjaksoille.

Jokaiselle indeksisarjalle estimoitiin autokorrelaatiofunktio. Yhtä kuusen indeksisarjaa lukuun ottamatta autokorrelaatiot viiveellä 1 olivat merkitseviä. Kokonaisuutena erot indeksisarjojen rakenteissa olivat kuitenkin huomattavia varsinkin männyllä.

Ilmastotekijöiden ja kasvuindeksien välisten riippuvuuksien tarkastelussa käytettiin korrelaatioanalyysiä, yksinkertaisia jakautuneiden viiveiden malleja ja siirtofunktio-kohinamalleja.

Tarkastelluista ilmastotekijöistä kuusen kasvuindeksejä selitti parhaiten kasvukauden lämpösumma. Edellisen kasvukauden loppuosan lämpimyys osoittautui indeksiä pienentäväksi. Männyn indeksisarjoille parhaita selittäjiä olivat kasvukauden loppuosan lämpimyys ja varsinkin karuimmilla kasvupaikoilla touko-heinäkuun sademäärä.

The paper concerns relationships between climatic factors and annual ring indices mainly in southern Finland. The studied index series were from papers of different authors and from different localities. The monthly mean temperatures and precipitation sums were derived from the measurements of meteorological stations. Effective temperature sums for different periods of the year were calculated from the monthly mean temperatures.

The autocorrelation functions were estimated for each index series. The autocorrelations at lag 1 were significant except for one series. Altogether the differences in the structures of the index series were noticeable, especially between the pine index series.

The influence of climatic factors on the annual ring index variation was studied using cross correlation analysis, simple distributed lag models and transfer function-noise models.

The decisive factor for the annual ring index variation of Norway spruce appeared to be the effective temperature sum of the growing season. Warm periods during latter parts of the previous summer had a negative effect on indices. For the variation of the Scots pine indices the most important climatic factors were the effective temperature sum of the latter part of the growing season and, especially on the arid sites, the precipitation sum during May-July.

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PREFACE

The present study constitutes the first part of an investigation on the relationship between climatic factors and variation in annual diameter growth of the main tree species in Finland. Dr. Pekka Kilkki and Mr. Risto Ojansuu, M.Sc. have provided useful criticism and advice during the work. Professor Yrjö Vuokila, Dr. Simo Poso and Mr. Markku Kanninen, Lic. for. have also read the manuscript and made valuable suggestions for improving it. The English text has been checked by Ms. Kathryn Keister, B.Sc.

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1. INTRODUCTION

11. Annual ring indices

The relative variation of the annual ring widths may be expressed by the annual ring indices i.e., the quotient of the measured and expected annual ring widths. The expected or 'normal' annual ring widths are usually estimated with smoothing functions (see Bräker 1981). The smoothed normal annual ring width is supposed to be the radial growth, which would have been attained in constant climatic conditions.

The values of the annual ring index series are usually not independent from each other, but there exists autocorrelation (Hustich and Elfving 1944, Eklund 1954) and cyclic variation (Douglass 1919, Boman 1927, Mikola 1950, Sirén 1961). The autocorrelation and cyclic variation are often considered as characteristics of the growth of Scots pine. Their importance increases at high latitudes (Eklund 1957) and high altitudes (LaMarche 1974). The long needle retention near the tree line has been suggested as an explanation for this phenomenon (LaMarche 1974, Hustich 1981). On the other hand, it is difficult to understand, why such an autocorrelation would not be found in the growth indices of Norway spruce (cf. Ording 1941).

The periodicity of annual growth is often connected with the rhythm of solar activity. There are, however, different opinions concerning the coincidence and causality of the cycles observed in the tree ring widths and the solar activity (Heikkinen 1980). For example, LaMarche and Fritts (1972) did not find any convincing evidence of consistent relationships between ring width and solar variation.

12. Environmental factors and annual rings

121. Climatic factors

In Finland the relationship between climate and tree rings has been studied by Laitakari (1920), Hustich and Elfving (1944), Mikola (1950), Sirén (1961) and Roiko-Jokela (1976) among others. These studies have been concentrated near the northern tree line, where the influence of climate is easier to observe, partly because the competition of the other trees is nearly eliminated (Hustich 1981). Since Scots pine is the main softwood tree species on the northern tree line in Finland it has been the main subject of the Finnish tree ring studies.

The studies indicate that the decisive climatic factor affecting the radial growth in northern conditions is the temperature of the growing season. The effect of deficient rainfalls is usually considered to be of minor importance. According to Mikola (1950) the lack of water affects the growth only in exceptionally dry summers on the driest sites. On the other hand, Kärenlampi (1972) and Roiko-Jokela (1976) in Finnish Lapland as well as Jonsson (1969) in Sweden, Slåstad (1957) in Norway and Holmsgaard (1955) in Denmark have observed the relationship between precipitation and the growth of trees even in northern conditions.

122. Non-climatic factors

The correlation between different climatic factors and growth indices has often proved to be insignificant except during exceptional growing seasons. This may be mainly due to the great number of factors affecting growth, but also to the properties of the annual ring indices. The index series are usually obtained by eliminating only the trend caused by aging of trees. Thus the indices contain, besides the climatic influences, effects of several environmental and internal factors on the variation of annual growth. Included in the index variation are damages caused by insects, fungi and storms as well as the effects of thinning and fertilization etc. In order to exclude the effects of factors mentioned above, the increment cores for annual ring indices are often collected in natural stands. However, it is not possible to eliminate the effects of aging and changes in the competitive position of trees on their growth reactions.

The seed crops affect strongly the increment of those species with large infrequent seed crops. Norway spruce, for example, is such a species. According to Holmsgaard (1955) the loss of the annual radial increment is 25–30 %. Chałupka et al. (1975) estimate the loss to be about 12–25 %. The results obtained from the effects of the cone crops on Scots pine diameter increment vary a lot. According to Hustich (1948) and Sirén (1961) increment losses occur in the year of cone maturation. Sirén (1961) reported that heavy cone crops affect the increment even in the summer following the cone maturation. Contrary to this, a lack of correlation between radial increment and cone yields has been reported by Eklund (1954) and Jonsson (1969). Chałupka et al. (1976) found that flowering slightly reduces the diameter increment, but the maturation of cones has no effect on the growth.

Eklund (1957) has given attention to the possible differences in the variation of growth in separate crown classes; the cone crops, for example, mainly affect the increment of dominant and co-dominant trees. The length of the growing season is also dependent on the competitive position of the tree. The growth of the dominant and co-dominant trees begins about two weeks earlier than the growth of the intermediate and suppressed trees. The growth of the trees belonging to the dominated crown classes also ceases earlier mainly because of the lack of water (Mitscherlich et al. 1966). Mikola (1950) has also noticed the differences in the gorwth of the dominating and dominated trees in dry summers. According to Klemmer (1969) the decisive period for the diameter increment of suppressed trees in a Norway spruce stand is the early part of summer while for the increment of dominating trees the conditions of the latter part of summer also are significant.

The effect of stand density on the growth is similar to that of the competitive position of trees. Trees in unthinned stands frequently have a shorter growing season than trees in thinned stands (Mitscherlich et al. 1966, Fritts 1976). Moreover, Eide (1926) and Eklund (1954) report no significant difference in the variation of annual ring indices between dense and sparse stands.

According to Eide (1926), Mikola (1950), Eklund (1954), and Müller (1981) the climatic variation of radial increment is similar on different sites. On the contrary, Slåstad (1957) has found clear differences in growth of stands located at a distance of only 100 m from each other. In Central Europe the site primarily determines whether the temperature or precipitation is the decisive factor for the annual variation of growth (Huber and v. Jazewitsch 1952).

The age of the tree has an obvious influence on the magnitude of the variation of radial increment. The absolute variation is greatest in young trees (Laitakari 1920) while the relative variation increases with age (Ilvessalo 1945, Mikola 1950). Young trees react distinctly to the conditions of each growing season while the lag effect of preceding summers is clearer in old trees (Mikola 1950, Holmsgaard 1955). Eklund (1944) has also reported that trees of different ages react in somewhat different ways.

13. Purpose of the study

The purpose of the present study is to establish the periods of the growing season during which the temperature and precipitation significantly affect the growth of Norway spruce and Scots pine in southern Finland.

The previous survey of the earlier literature on the factors affecting the annual ring indices clearly demonstrates the great disagreement of different research results. One explanation may be the inadequate analytical tools used in these studies.

2. MATERIAL

21. Annual ring indices

The material comprised 7 annual ring index series of Norway spruce and 12 series of Scots pine. The following spruce series have been published by Thammincha (1981): Ruotsinkylä, Simpele, Hyytiälä, Kuorevesi, Parkano and Koli. These series cover the period 1910–1977. The index series of Kuru – Ruovesi for the period 1881–1945 (Mikola 1950) was used as an auxiliary material.

Six of the studied Scots pine series were chosen from the paper of Thammincha (1981): Ruotsinkylä, Hyytiälä, Koli 1, Koli 2, Karvia and Punkaharju. In addition, six local index series were obtained from the Rovaniemi experimental station of the Finnish Forest Research Institute: Ruotsinkylä, Koli, Mänttä, Savonlinna, Ylivieska and Pallasjärvi, which is the only one of the studied index series located in northern Finland. These six series cover the period 1900–1978.

The location of the index series data is illustrated in Fig. 1. Some information about the basic material used in the construction of the index series of Thammincha (1981) is presented in tables 1 and 2.

The autoregressive properties of all series mentioned above were studied. The analysis of the covariation of climate and the radial growth of spruce was based on the index series of Kuru – Ruovesi and the above mentioned series of Thammincha (1981) excluding Kuorevesi. For the index series of pine the series of Thammincha and the Pallasjärvi material of the Forest Research Institute were employed.

22. Climatic data

Monthly mean temperatures and precipitation sums were derived for each locality from the meteorological stations data using the method of Ojansuu and Henttonen (1983). Based on the monthly mean temperatures the effective temperature sums, with the minimum temperature 5°C, were calculated for seven calendar periods of the year.

In addition, the proper climatic factors describing the following phases of the growing seasons were derived (Jonsson 1969):

Phase 1: Neither shoot nor diameter growth
Phase 2: Both shoot and diameter growth
Phase 3: Diameter growth only
Phase 4: Neither shoot nor diameter growth

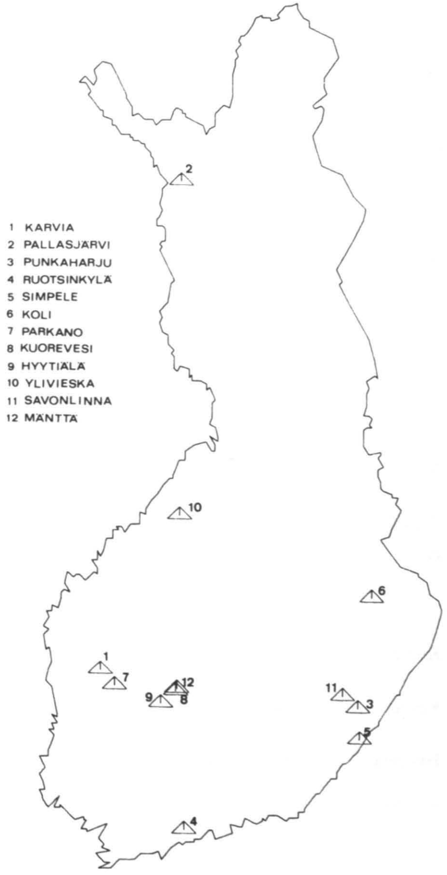


Figure 1. The localities of annual ring index series.
Kuva 1. Paikallisten vuosilustoindeksisarjojen sijainti.

Table 1. Some characteristics of the basic material used for the spruce index series of Thammincha (1981).
Taulukko 1. Thamminchan (1981) kuusen indeksisarjojen laadinta-aineistoa koskevia tietoja.

index series *indeksisarja*	sample plots *koealoja*	sample trees – *koepuita*			age – *ikä*		thinnings *harvennukset*	fertilizations *lannoitukset*
		total *yht.*	in different sites *eri kasvupaikoilla* %		min *min*	max *max*		
			OMT	MT				
Ruotsinkylä	11	147	48	52	50	173	1953, 1956, 1958, 1959, 1960, 1963, 1965, 1967, 1969, 1971	
Simpele	8	108		100	107	136		
Koli	10	195	62	38	58	141	1953, 1954, 1955, 1957, 1965, 1966, 1969, 1970, 1971	
Parkano	4	99	27	73	90	114		
Hyytiälä	13	263	42	58	84	125	1960, 1964	1965, 1966, 1967, 1968, 1969, 1971, 1974

Table 2. Some characteristics of the basic material used for the pine index series of Thammincha (1981).
Taulukko 2. Thamminchan (1981) männyn indeksisarjojen laadinta-aineistoa koskevia tietoja.

index series *indeksisarja*	sample plots *koealoja*	sample trees – *koepuita*					age – *ikä*		thinnings *harvennukset*	fertilizations *lannoitukset*
		total *yht.*	in different sites *eri kasvupaikoilla* %				min *min*	max *max*		
			OMT	MT	VT	CT				
Ruotsinkylä	8	77	3	54		43	53	145	1947. 1954, 1956, 1960, 1967, 1969	
Punkaharju	13	157	3	41	56		71	161	?	
Koli 1	11	140		21	71	8	59	146	1950, 1951, 1952, 1953, 1959, 1960, 1961, 1962, 1963, 1969, 1972	
Koli 2	5	86		2	98		77	121	1953, 1954, 1955, 1965, 1966, 1970	
Karvia	6	123			36	64	46	107	1957, 1960, 1961, 1966, 1975	
Hyytiälä	12	157	11	26	38	25	71	128	1959, 1960	1966, 1967, 1968, 1969, 1971

Based on the studies of Raulo and Leikola (1975) and Leikola (1969) an effective temperature sum limit was fixed to be the starting point of phase 2. This limit was chosen to be 50 d.d. As the termination of the principal diameter growth seems to be independent of temperature (Leikola 1969), a constant date, 15. 8., was fixed to be the last day of phase 3 (cf. Romell 1925, Andersson 1953). The first day of phase 3 was determined to be the midpoint between the first day of phase 2 and the last day of phase 3 (see Jonsson 1969).

The following climatic variables were used in the analysis:

x1 = mean temperature of April
x2 = effective temperature sum 16. 5. – 31. 5.
x3 = " 1. 6. – 30. 6.
x4 = " 1. 7. – 31. 7.
x5 = " 1. 8. – 15. 8.
x6 = " 1. 6. – 31. 7.
x7 = " 1. 7. – 15. 8.
x8 = " 1. 1. – 31. 12.
x9 = the first day of the phase 2
x10= " 3
x11= the effective temperature sum of the phase 2
x12= " 3
x13= " 4
x14= the precipitation sum of May
x15= " June
x16= " July
x17= " August
x18= " May – July

The final results have been calculated on the VAX-11 computer of the Finnish Forest Research Institute. The BMDP programs 2T (Box-Jenkins Time Series Analysis) and 1R (Multiple Linear Regression) were used.

3. METHODS

In order to study the autoregressive properties of the annual ring indices the autocorrelation and partial autocorrelation functions were estimated and ARIMA (autoregressive-integrated-moving average) models fitted for each index series. The influence of different climatic factors on the annual ring variation was studied using the methods of cross correlation analysis, distributed lag models and transfer function – noise models.

A brief summary of the most essential features of the utilized methods will be given here. For more detailed presentation of ARIMA models see for example Box and Jenkins (1976), Anderson (1976) and Leskinen (1977). The techniques of cross correlation analysis and transfer function-noise model building are presented by Box and Jenkins (1976), Leskinen (1974) and Leskinen (1977). Distributed lags are discussed by Öller (1977) among others. The following summary is based upon the above mentioned studies. Specific references have been omitted from the text.

31. Distributed lags

The general finite distributed lag model may be stated as

$$z_t = \sum_{i=b}^{n} w_i x_{t-i} + u_t$$

where w_i are unknown nonzero constants, x_t is an exogenous variable, and u_t is a random variable independent of x_t, having a mean of zero and constant variance; b and n are respectively the minimal and the maximal length of the lag.

In principle, the application of ordinary least squares techniques will yield the best linear unbiased estimators of the lag coefficients under the standard assumptions of the error term and the explanatory variables.

If the minimal and the maximal length of the lag are a priori unknown, one may determine the lags incorporated in the model by starting the least squares estimation with a great number of lags, test the significance of the parameter estimates and exclude the lags which are not significant. However, if data are autocorrelated, a regression in which the explanatory variables are $x_{t-b}, \ldots, x_{t-n}$ is unlikely to yield satisfactory results. The autocorrelation leads to multicollinearity between independent variables which again results in unfitness of the selection criterion based on the t-test. However, in this study only the elimination method described above was used.

32. Building ARIMA models

In statistical theory, the observed time series is considered as one possible realization of a stochastic process, which represents the mechanism generating it. The stationary processes (see e.g. Box and Jenkins 1976 p. 26) are an important class of stochastic processes. They are assumed to be in the specific form of a statistical equilibrum, and in particular, vary about a fixed mean.

A time series in which successive values are highly dependent can be regarded as generated from a series of independent shocks $\{a_t\}$.These shocks are random drawings from a fixed distribution, usually assumed normal and having a mean of zero and variance σ_a^2. Such a sequence of random variables a_t, a_{t-1}, a_{t-2}, ... is called a *white noise* process.

The white noise process $\{a_t\}$ is transformed to the process $\{z_t\}$ by what is called a *linear filter.* The linear filtering operation simply takes a weighted sum of previous observations, so that

$$\begin{aligned}\tilde{z}_t &= a_t + \psi_1 a_{t-1} + \psi_2 a_{t-2} + \ldots \\ &= \psi(B) a_t \qquad (32.1)\end{aligned}$$

where

$$\tilde{z}_t = z_t - \mu$$
$$\psi(B) = 1 + \psi_1 B + \psi_2 B^2 + \ldots$$
$$Ba_t = a_{t-1},\ B^m a_t = a_{t-m}$$
$$Ea_t = 0,\ D^2 a_t = \sigma_a^2,\ \mathrm{cov}(a_t, a_{t+s}) = 0, s \neq 0$$

$\{z_t\}$ is the output process of the system. ψ (B)is the linear operator (filter) that transforms $\{a_t\}$ into $\{z_t\}$. The representations of the general linear process would not be very useful in practice, if they contained an infinite number of parameters. For practical representation, it is desirable to employ models which use parameters parsimonously. Parsimony may often be achieved by representation of the linear process in terms of a small number of autoregressive and moving average terms.

A model which often is useful in the representation of practically occurring series is the autoregressive model which expresses the current value of the process as a finite linear aggregate of previous values of the process and a shock a_t such that:

$$\tilde{z}_t = \phi_1 \tilde{z}_{t-1} + \phi_2 \tilde{z}_{t-2} + \ldots + \phi_p \tilde{z}_{t-p} + a_t \qquad (32.2)$$

Model (32.2) is called an *autoregressive (AR) process of order p* and it may be written as

$$\phi(B) \tilde{z}_t = a_t \qquad (32.3)$$

where $\phi(B) = 1 - \phi_1 B - \ldots - \phi_p B^p$ is termed the AR(p) operator. (32.3) implies

$$\tilde{z}_t = \frac{1}{\phi(B)} a_t = \phi^{-1}(B) a_t \qquad (32.4)$$

Thus, the autoregressive process can be thought of as the output $\{z_t\}$ from a linear filter with transfer function $\phi^{-1}(B)$ when the input is white noise.

The *moving average model of order q*, the MA(q) process, is given by

$$\tilde{z}_t = a_t - \theta_1 a_{t-1} - \ldots - \theta_q a_{t-q} \qquad (32.5)$$

which may be written

$$\tilde{z}_t = \theta(B) a_t$$

where $\theta(B) = 1 - \theta_1 B - \ldots - \theta_q B^q$ is MA(q) operator.

An extension to the AR and MA models is the *mixed autoregressive -moving average model* (ARMA) of the form

$$\tilde{z}_t = \phi_1 \tilde{z}_{t-1} + \ldots + \phi_p \tilde{z}_{t-p} + a_t - \theta_1 a_{t-1} - \ldots - \theta_q a_{t-q} \qquad (32.6)$$

or

$$\phi(B) \tilde{z}_t = \theta(B) a_t$$

Many actual time series exhibit nonstationary behaviours and in particular do not vary about a fixed mean. Such series may nevertheless exhibit a certain homogeneity and can be accounted for by a modification of the ARMA model resulting in the *autoregressive integrated moving average model.* This ARIMA(p,d,q) model is written

$$w_t = \phi_1 w_{t-1} + \ldots + \phi_p w_{t-p} + a_t - \theta_1 a_{t-1} - \ldots - \theta_q a_{t-q} \qquad (32.7)$$

where $w_t = \nabla^d z_t$, $\nabla\ z_t = z_t - z_{t-1}$

(32.7) may be written

$$\varphi(B) \tilde{z}_t = \theta(B) a_t$$

where $\varphi(B)$ is the generalised autoregressive operator $\varphi(B) = \phi(B)(1-B)^d$. The ARIMA model includes the stationary mixed model (ARMA), the pure autoregressive model (AR), and the pure moving average model (MA) as special cases.

For time series which show a seasonal pattern with period s Box and Jenkins (1976) give the general multiplicative model

$$\phi_p(B) \Phi_P(B^s) \nabla^d \nabla_s^D z_t = \theta_q(B) \Theta_Q(B^s) a_t \qquad (32.8)$$

where $\Phi_P(B)^s = 1 - \Phi_1 B^s - \ldots - \Phi_P B^{Ps}$
is the seasonal autoregressive operator of order P
$\Theta_Q(B^s) = 1 - \Theta_1 B^s - \ldots - \Theta_Q B^{Qs}$
is the seasonal moving average operator of order Q
$\nabla_s^D = (1 - B^s)^D$
is the seasonal difference operator applied D times.

The resulting multiplicative process is said to be of order $(p,d,q) \times (P,D,Q)_s$.

321. Autocorrelation and partial autocorrelation

The covariance between z_t and z_{t+k}, separated by k interals of time, is called the *autocovariance at lag k:*

$$\mathrm{cov}(z_t, z_{t+k}) = \gamma_k.$$

The *autocorrelation at lag k* is defined by

$$\varrho_k = \frac{\mathrm{cov}(z_t, z_{t+k})}{\sqrt{\mathrm{var}\ (z_t) \mathrm{var}(z_{t+k})}}$$

which may be written

$$\varrho_k = \frac{\gamma_k}{\sigma_z^2}$$

since, for a stationary process, the variance σ_z^2 is the same at time $t+k$ as at time t. The plot of the autocorrelation coefficient as a function of the lag is called the *autocorrelation function.*

A number of estimates of the autocorrelation function have been suggested. Box and Jenkins consider the most satisfactory estimate of the k^{th} lag autocorrelation ϱ_k

$$r_k = \frac{c_k}{c_0} \qquad (32.9)$$

where

$$c_k = \frac{1}{n} \sum_{t=1}^{n-k} (z_t - \bar{z})\,(z_{t+k} - \bar{z}) \qquad k=0,\ 1,\ 2,\ \ldots,\ K$$

is the estimate of the autocovariance γ_k, where $\bar{z}$ is the mean of the time series z_1, z_2, …, z_n of n observations. To obtain a useful estimate of the autocorrelation function n will have to be sufficiently large, at least 50 observations are usually required; r_k should not be calculated for $k>n/4$.

To identify a model for a time series it is necessary to have a check on whether ϱ_k is effectively zero beyond a certain lag. Bartlett's approximation (see e.g. Leskinen 1977 p.84) gives, for a stationary normal series, assuming $\varrho_k=0$ for all $k>q$,

$$\text{var}\ (r_k) = \frac{1}{n}\ (1+2 \sum_{v=1}^{q} \varrho_v^2), \qquad k>q \qquad (32.10)$$

In practice, one usually has to replace ϱ_v by r_v in (32.10). The square root of var (r_k) is then the large standard error of r_k.

Another tool, which will be needed in model building, is the *partial autocorrelation function*, denoted by $\{\phi_{kk}\colon k=1,2,\ldots\}$, the set of partial autocorrelations at various lags k. These are defined by the equations

$$\varrho_j = \phi_{k1}\varrho_{j-1} + \ldots + \phi_{k(k-1)}\varrho_{j-k+1} + \phi_{kk}\varrho_{j-k} \qquad j=1,2,\ldots,k$$

where ϕ_{kj} is the j^{th} coefficient in the autoregressive process of order k, so that ϕ_{kk} is the last coefficient. Estimates $\hat{\phi}_{kk}$ can be obtained by replacing the ϱ_i by r_i. At lags large enough for the partial autocorrelation function to have died out, the variance of the estimated partial autocorrelations is approximately

$$\text{var}(\hat{\phi}_{kk}) \simeq \frac{1}{n} \qquad k>p \qquad (32.11)$$

For fairly large values of n, $\hat{\phi}_{kk}$ is approximately normally distributed.

322. Model identification and checking

Model building can be seen as a three stage iterative process based on *identification, estimation* and *diagnostic checking.*

Model identification consists of two main stages:

a) *Identification of the degree of differencing.* A tendency for the autocorrelation function not to die out quickly is an indicator of nonstationarity. Thus, it is assumed that the degree of differencing d, necessary to achieve stationarity, has been reached when the autocorrelation function of $w_t = \nabla^d z_t$ dies out fairly quickly.
b) *Identification of the resulting ARMA process.* The estimated autocorrelation and partial autocorrelation functions should indicate the model to be employed. This is done by studying their general appearance and cutoffs. As the autocorrelation function of an autoregressive process of order p tails off, its partial autocorrelation function has a cutoff after lag p. For example, the theoretical autocorrelation function of the first-order autoregressive process decays exponentially to zero when ϕ_{11} is positive, but decays exponentially to zero and oscillates in sign when ϕ_{11} is negative. The partial autocorrelation function ϕ_{kk} of an AR(1) process is zero for $k>1$ and $\phi_{11}=\varrho_1$.

Conversely, the autocorrelation function of a moving average process of order q has a cutoff after lag q, while its partial autocorrelation function tails off. Examples of theoretical patterns for some AR(p), MA(q), and ARMA(p,q) processes are presented in Anderson (1976) on pages 16–17, 20–23, 34–35,38–41, 46–51.

The autocorrelation function and partial autocorrelation function are also used to obtain initial estimates of the parameters for the iterative estimation procedures.

After the parameters have been estimated, the fitted model will be subjected to diagnostic checks of its adequacy. One technique which can be used for diagnostic checking is overfitting which assumes knowledge about the kind of discrepancies. Procedures less dependent on such knowledge are based on the analysis of residuals. The study of the estimated autocorrelation function of the estimated residuals $\{\hat{a}_t\}$ could indicate the existence and nature of model inadequacy. If the model is adequate, the $\hat{a}_t$ values come close to the white noise $\{a_t\}$, as the series length increases. Recognizable patterns in the estimated autocorrelation function of the estimated residuals $\{\hat{a}_t\}$ point to appropriate modifications of the model.

33. Building transfer function-noise models

The dynamic relationship connecting an input $\{x_t\}$ and an output $\{y_t\}$ can be represented in terms of a linear filter

$$\begin{aligned} y_t &= v_0x_t + v_1x_{t-1} + v_2x_{t-2} + \ldots \\ &= v(B)x_t \end{aligned} \qquad (33.1)$$

where $v(B)$ is the transfer function of the filter. $v(B)$ can be represented by the ratio of two polynomials

$$v(B) = \delta^{-1}(B)\omega(B)B^b$$

where

$$\delta(B) = 1-\delta_1B- \ldots -\delta_rB^r$$
$$\omega(B) = \omega_0-\omega_1B- \ldots -\omega_sB^s$$

In practice, the output $\{y_t\}$ could not be expected to follow exactly the pattern determined by the transfer function model, even if that model were entirely adequate. Disturbances other than $\{x_t\}$ normally corrupt the system. If the disturbance, or *noise* $\{n_t\}$, is assumed independent of $\{x_t\}$ then

$$y_t = \delta^{-1}(B)\omega(B)B^bx_t + n_t \qquad (33.2)$$

If the noise model can be represented by an ARIMA (p,d,q) process the model may be written finally as

$$y_t = \delta^{-1}(B)\omega(B)B^bx_t + \phi^{-1}(B)\theta(B)n_t \qquad (33.3)$$

The three stages of model building are again identification, estimation, and diagnostic checks. Similarly to the use of the autocorrelation function in the identification of the ARIMA models the cross correlation function between the input and output is employed for the identification of transfer function models.

The quantity

$$\varrho_{xy}(k) = \frac{\gamma_{xy}(k)}{\sigma_x\sigma_y} \qquad k = 0,\pm1,\pm2,\ldots$$

where $\gamma_{xy}(k)$ is the cross covariance coefficient between x and y at lag $+k$, is called the *cross correlation coefficient* at lag k, and the function $\varrho_{xy}(k)$ defined for $k=0,\pm1,\pm2,\ldots$, is the *cross correlation function* of the bivariate process. The cross correlation function, in contrast to the autocorrelation function, is not symmetric about $k=0$. An estimate $r_{xy}(k)$ of the cross correlation coefficient at lag k is provided by

$$r_{xy}(k) = \frac{c_{xy}(k)}{s_xs_y} \quad k = 0,\pm1,\pm2,\ldots \qquad (33.4)$$

where

$$c_{xy}(k) = \begin{cases} \dfrac{1}{n}\displaystyle\sum_{t=1}^{n-k} (x_t-\bar{x})(y_{t+k}-\bar{y}) & k=0,1,2,\ldots \\ \dfrac{1}{n}\displaystyle\sum_{t=1}^{n-k} (y_t-\bar{y})(x_{t+k}-\bar{x}) & k=0,-1,-2,\ldots \end{cases}$$

$$s_x = \sqrt{c_{xx}(0)}$$
$$s_y = \sqrt{c_{yy}(0)}$$

A crude check as to whether certain values of the cross correlation function could be effectively zero may be made by comparing the corresponding cross correlation estimates with their approximate standard error derived from Bartlett's formula for different special cases (see e.g. Box and Jenkins 1976 p. 376). In particular, when two processes are not cross correlated and one is white noise

$$\text{var}(r_{ay}(k)) \approx \frac{1}{(n-k)} \qquad (33.5)$$

The objective of the identification stage is to obtain some idea of the orders r and s of the operators $\delta(B)$ and $\omega(B)$ in the transfer function model, and the delay parameter b. The identification procedure consists of:

a) deriving rough estimates $\hat{v}_j$ of the impulse response weights v_j,
b) using estimates $\hat{v}_j$ to make guesses of the orders r,s and the delay parameter b; values b,r, and s may be guessed using the following facts about the impulse response weights v_j

i) b zero values $v_0, v_1, \ldots, v_{b-1}$

ii) further $s-r+1$ values $v_b, v_{b+1}, \ldots, v_{b+s-r}$ follow no fixed pattern

iii) values v_j with $j>b+s-r+1$ follow the pattern dictated by an r^{th} order difference equation.

c) using $\hat{v}_j$ with values of r, s, and b to obtain initial estimates of the parameters δ and ω.

Details of transfer function models for combinations of $r=0, 1, 2$ and $s=0, 1, 2$ are presented in Box and Jenkins (1976) p. 346–351.

If the original input is not white noise but follows some other stochastic process, Box and Jenkins suggest the prewhitening of the input to be employed in identification of transfer function models. If the input process $\{x_t\}$ is stationary and can be represented by some member of the class of ARMA models, it is possible to use usual identification and estimation methods to obtain a model for the $\{x_t\}$ process

$$\alpha_t = \phi_x(B)\theta_x^{-1}(B)x_t$$

which transforms the correlated input series into the uncorrelated white noise series α_t. The same transformation is applied to $\{y_t\}$,

$$\beta_t = \phi_x(B)\theta_x^{-1}(B)y_t$$

and model (33.2) may be written

$$\beta_t = v(B)\alpha_t + \varepsilon_t \qquad (33.6)$$

The relationship connecting v(B) and the cross correlation function is obtained from (33.6)

$$v_k = \frac{\varrho_{\alpha\beta}(k)\sigma_\beta}{\sigma_\alpha} \quad k = 0,1,2,\ldots \qquad (33.7)$$

In practice, estimates are used to give

$$\hat{v}_k = \frac{r_{\hat{\alpha}\hat{\beta}}(k)s_{\hat{\beta}}}{s_{\hat{\alpha}}} \quad k = 0,1,2,\ldots$$

Having obtained a preliminary estimate v(B) of the transfer function an estimate of the noise series is provided by

$$\hat{n}_t = y_t - v(B)x_t$$

Study of the estimated autocorrelation function of $\{\hat{n}_t\}$ is then used to identify the noise model.

The adequacy of the fitted transfer function-noise model is usually checked by examining

a) the autocorrelation function of the residuals from the fitted model

b) the cross correlation function between (prewhitened) input and the residuals.

If the transfer function model is correct but the noise model is incorrect the residuals would not be cross correlated with input series. However the residuals would be autocorrelated and the form of the estimated autocorrelation function could indicate appropriate modification of the noise structure. If the transfer function model were incorrect the residuals would be cross correlated with the (prewhitened) input series and also autocorrelated. Whether or not the noise model was correct, a cross correlation analysis could indicate the modifications needed in the transfer fuction model.

4. RESULTS

41. The properties of annual ring index series

411. Norway spruce

The estimated autocorrelations and partial autocorrelations for the studied Norway spruce index series of Thammincha (1981) are presented in Figs. 2 and 3. In the Kuru – Ruovesi series of Mikola (1950) neither significant autocorrelations nor significant partial autocorrelations were found. ARIMA models were identified and their parametres estimated for each series (Appendix 1). The final models were AR(1) excluding the Kuorevesi series which appeared to be AR(2).

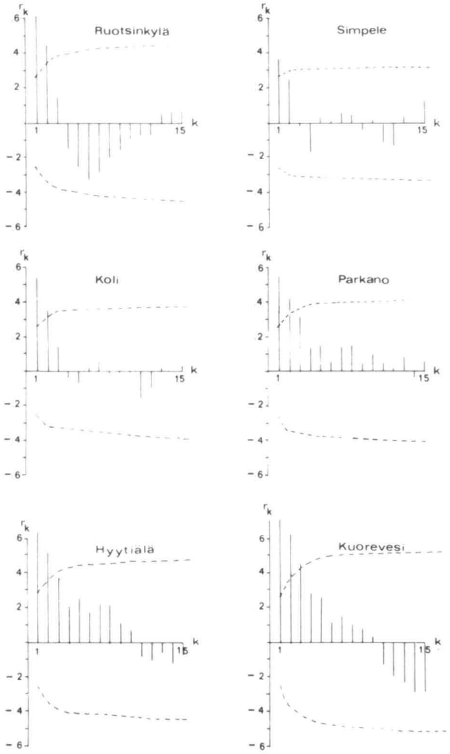


Figure 2. The estimated autocorrelations versus the lag k (k=1, . . . ,15) for the local Norway spruce index series of Thammincha (1981). (-----) = 2S.E.(r_k).

Kuva 2. Thamminchan (1981) paikallisten kuusen vuosilustoindeksisarjojen autokorrelaatioiden estimaatit viiveen k arvoilla 1–15. (-----) = 2S.E.(r_k).

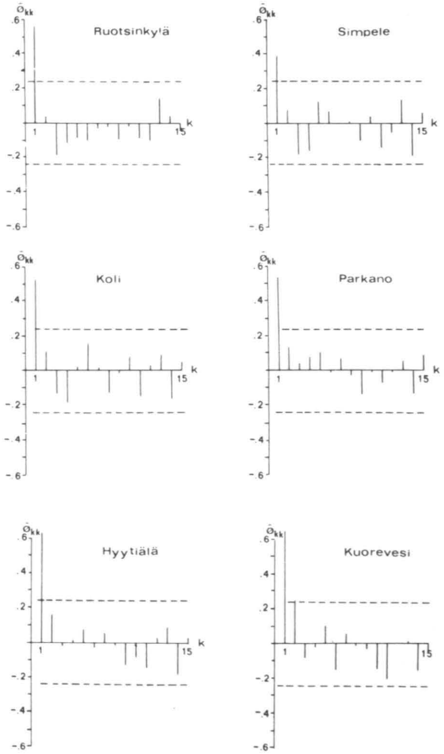


Figure 3. The estimated partial autocorrelations versus the lag k (k=1, . . . ,15) for the local Norway spruce index series of Thammincha (1981). (-----) = 2S.E.($\hat{\phi}_{kk}$).

Kuva 3. Thamminchan (1981) paikallisten kuusen vuosilustoindeksisarjojen osittaisautokorrelaatioiden estimaatit viiveen k arvoilla 1–15. (-----) = 2S.E.($\hat{\phi}_{kk}$).

In order to study the covariation between annual ring indices from different localities, the correlations were calculated both between the original indices and between the index series prewhitened with ARIMA models presented in Appendix 1 (Fig. 4). The correlation between prewhitened series was on average higher ($\bar{r}$ = .60) than between the original series ($\bar{r}$ = .46) and the dependence of the correlation on the distance was clear in the prewhitened series.

412. Scots pine

The estimated autocorrelations and partial autocorrelations for the studied Scots pine index series of Thammincha (1981) are presented in Figs. 5 and 6. The identified and estimated ARIMA models for these series are in Appendix 1. The final results were AR(1)-models except the Ruotsinkylä and Karvia series which had cyclic variation. The correlations between annual ring indices from different localities are presented in Fig. 8. The average correlation between the original indices was .45 and between the prewhitened series .53.

In the indices of the Forest Research Institute the differences in the structure of autocorrelation functions from separate localities were noticeable (Fig. 7). The material from Mänttä and Koli may be described by an AR(1) process while the series of Ruotsinkylä seems to indicate a cyclic pattern. The estimated autocorrelations for Parkano, Ylivieska and Savonlinna decrease slowly from 1, which suggests a trend.

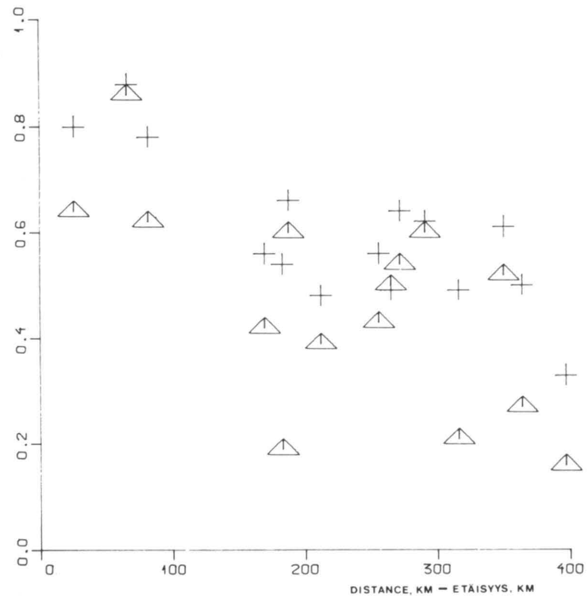


Figure 4. Correlation between the local Norway spruce index series of Thammincha (1981) as a function of the distances between the localities. (△) = original index series. (+) = index series prewhitened with ARIMA models.

Kuva 4. Thamminchan (1981) paikallisten kuusen indeksisarjojen väliset korrelaatiot (r) etäisyyden funktiona. (△) = alkuperäiset indeksisarjat. (+) = ARIMA malleilla esivalkaistut indeksisarjat.

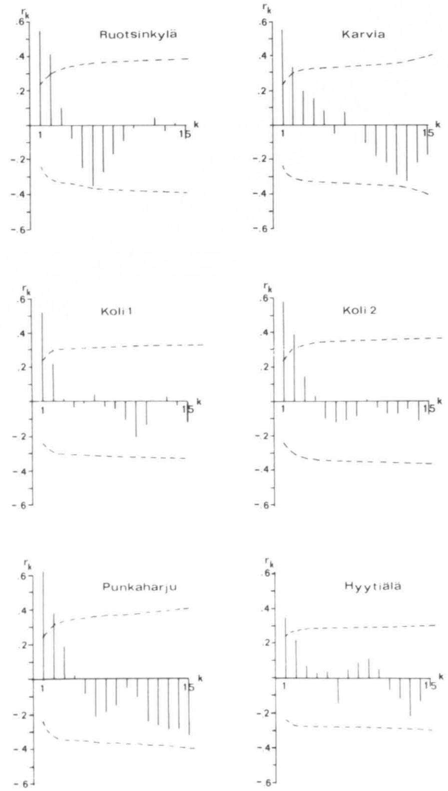


Figure 5. The estimated autocorrelations versus the lag k (k=1, . . . ,15) for the local Scots pine index series of Thammincha (1981). (-----) = 2S.E.(r_k).

Kuva 5. Thamminchan (1981) paikallisten männyn vuosilustoindeksisarjojen autokorrelaatioiden estimaatit viiveen k arvoilla 1–15. (-----) = 2S.E.(r_k).

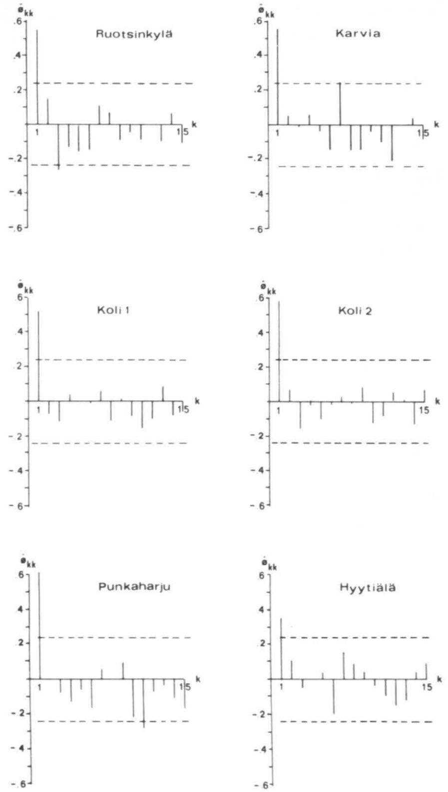


Figure 6. The estimated partial autocorrelations versus the lag k (k=1, . . . ,15) for the local Scots pine index series of Thammincha (1981). (-----) = 2S.E.($\hat{\phi}_{kk}$).

Kuva 6. Thamminchan (1981) paikallisten männyn vuosilustoindeksisarjojen osittaisautokorrelaatioiden estimaatit viiveen k arvoilla 1–15. (-----) = 2S.E.($\hat{\phi}_{kk}$).

42. The dependence of annual ring indices on effective temperature sum and precipitation

421. Distributed lag models

In order to reduce the inaccuracy involved in the first and last terms of annual ring index series (cf. Strand 1969, Jonsson and Hägglund 1979), a five year period was cut off from the beginning and from the end of each time series studied. To make the models for separate localities comparable, the values of independent variables were divided by their averages and multiplied by 100. The transformed variables are written here in capital letters.

The preliminary selection of input variables for regression models was carried out by cross correlation analysis. Estimated cross correlations between the logarithms of climatic factors and annual ring indices are given in Tables 3 and 4 and in Figs. 10, 11, 12 and 14.

The estimated parameters of the following models for the indices (Y_t) of Norway spruce are presented in Tables 5, 6 and 7:

$$\ln(Y_t) = \beta_0+\beta_1\ln(X8_t)+\beta_2\ln(X18_t)+\varepsilon_t \qquad (42.1)$$

$$\ln(Y_t) = \beta_0+\beta_1\ln(X8_t)+\beta_2\ln(X18_t)+\beta_3\ln(X7_{t-1}) +\beta_4\ln(X18_{t-1})+\varepsilon_t \qquad (42.2)$$

$$\ln(Y_t) = \beta_0+\beta_1\ln(X11_t)+\beta_2\ln(X12_t)+\beta_3\ln(X18_t) +\beta_4\ln(X12_{t-1})+\beta_5\ln(X18_{t-1})+\varepsilon_t \qquad (42.3)$$

Since the effective temperature sum of the latter part of the growing season (variable X12) proved to correlate better than the temperature sum of the whole growing season with the indices of Scots pine, the parameters of the following models are presented besides models (42.3) in Tables 8, 9 and 10:

$$\ln(Y_t) = \beta_0+\beta_1\ln(X12_t)+\beta_2\ln(X18_t)+\varepsilon_t \qquad (42.4)$$

$$\ln(Y_t) = \beta_0+\beta_1\ln(X12_t)+\beta_2\ln(X18_t)+\beta_3\ln(X12_{t-1}) +\beta_4\ln(X18_{t-1})+\varepsilon_t \qquad (42.5)$$

Except the Kuru – Ruovesi spruce series the employment of mere climatic factors as independent variables resulted in high residual autocorrelations. In order to avoid this phenomenon the previous year's index was incorporated as a variable in the model (cf. Holmsgaard 1955, Jonsson 1969, Roiko-Jokela 1976). The estimated parameters for the models involving the previous year's index are given in Tables 5. . . 10. The use of the preceding index, however, increased the correlation between parameter estimates and made the assessment of the importance of the previous year's climatic factors impossible.

The correlations between the parameter estimates corresponding to the climatic factors of the growing season were anyway rather low and it was thus possible to draw some kind of conclusions about them. The effective temperature sum is clearly the decisive factor affecting the annual ring variation of Norway spruce. There seems to be no difference between the different parts of the growing season. For the Scots pine in southern Finland the most important factor affecting radial increment variations is either the effective temperature sum of the latter part of the growing season (period 3) or the precipitation sum in May – July. In the Pallasjärvi series there is no correlation between precipitation and annual ring width variation.

The determination of the annual ring indices on the basis of weather alone was tested using the models (42.2) and (42.3). New indices for Ruotsinkylä, Simpele, Koli, Hyytiälä and Parkano were calculated using the parameters estimated for the Kuru – Ruovesi spruce series covering the period 1881 – 1940. The mean of these climate-based indices was compared with the actual mean index of test material, which comprised the five index series mentioned above (Fig. 9), with the indices for southern Finland published by Thammincha (1981), and with the indices based on the material of the 3^{rd} (Ilvessalo

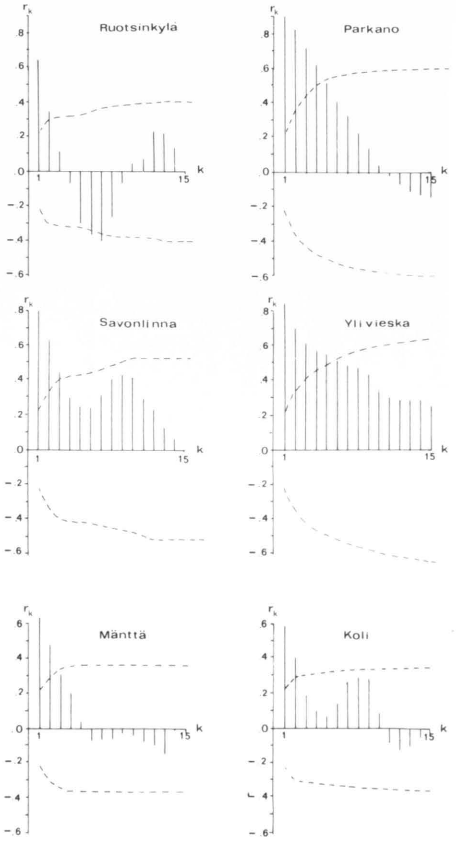


Figure 7. The estimated autocorrelations versus the lag k (k=1, . . . ,15) for the local Scots pine index series of the Forest Research Institute. (-----) = 2S.E.(r_k).

Kuva 7. Metsäntutkimuslaitoksen paikallisten männyn vuosilustoindeksisarjojen autokorrelaatioiden kuvaajat viiveen k arvoilla 1–15. (-----) = 2S.E.(r_k).

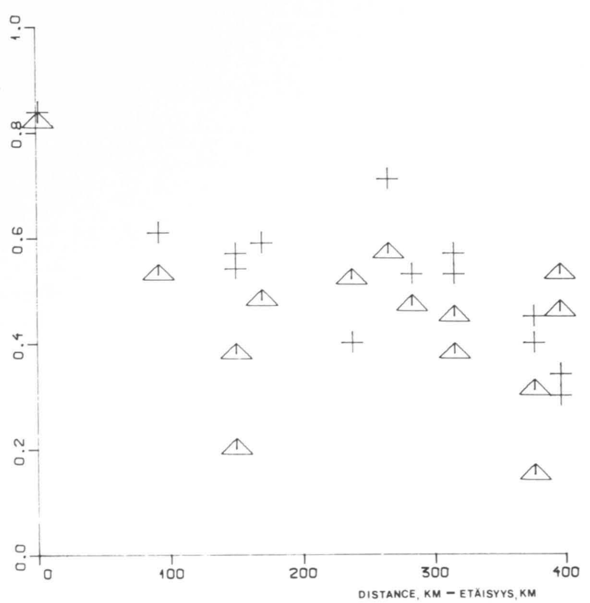


Figure 8. Correlation between the local Scots pine index series of Thammincha (1981) as a function of the distances between the localities. (△) = original index series. (+) = index series prewhitened with ARIMA models.

Kuva 8. Thamminchan (1981) paikallisten männyn vuosilustoindeksisarjojen väliset korrelaatiot etäisyyden funktioina. (△) = alkuperäiset indeksisarjat. (+) = ARIMA-malleilla esivalkaistut indeksisarjat.

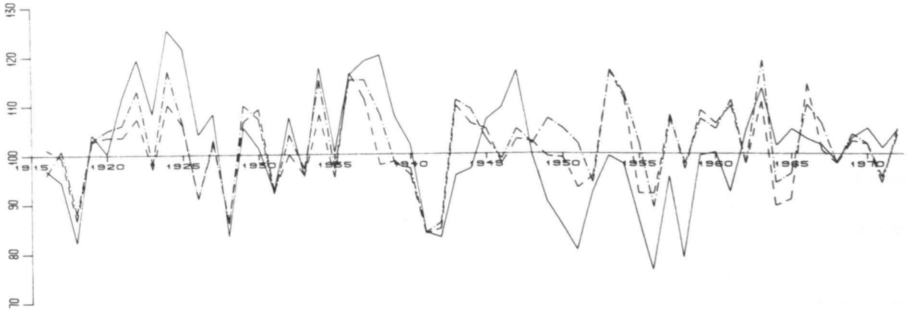


Figure 9. The average (——) of the Simpele, Parkano, Hyytiälä, Koli and Ruotsinkylä index series compared with the averages of indices calculated for the same localities with the models (42.2) (-·-·-) and (42.3) (-----) with the parameters estimated in Kuru-Ruovesi material.

Kuva 9. Simpeleen, Parkanon, Hyytiälän, Kolin ja Ruotsinkylän paikallisten indeksisarjojen keskiarvon (——) vertailu Kurun-Ruoveden malleilla (42.2) (-·-·-) ja (42.3) (-----) samoille paikkakunnille laskettujen indeksisarjojen keskiarvoon.

Table 3. Estimated cross correlation between climatic factors and annual ring indices of Norway spruce. See page 9 for the symbols of variables.

Taulukko 3. Ilmastotietojen ja kuusen vuosilustoindeksien välisten ristikorrelaatioiden estimaatteja. Muuttujaluettelo sivulla 9.

variable *muuttuja*	lag *viive*	index series – *indeksisarja*						2 S.E. ($r_{xy}(k)$)	
	k	Kuru	Ruotsinkylä	Simpele	Koli	Hyytiälä	Parkano		
				r_{xy} (k)					
ln(x1)	0	.07	.25	.31	.19	–.06	–.07	.26	.26
	1	–.11	.29	.27	.12	.02	.03	.26	.26
	2	.13	.23	.14	.00	–.03	.03	.27	.26
ln(x2)	0	.41	.11	.30	.22	.28	.33	.26	.26
	1	.04	.10	.14	–.02	.15	.08	.26	.26
	2	–.01	.01	–.08	–.10	.04	.00	.27	.26
ln(x3)	0	.44	.32	.20	.08	.14	.14	.26	.26
	1	–.16	.31	.08	–.07	.01	–.14	.26	.26
	2	–.10	.22	–.02	–.25	.08	–.08	.27	.26
ln(x4)	0	.20	.16	.37	.18	.49	.36	.26	.26
	1	–.44	–.08	–.11	–.17	.12	–.01	.26	.26
	2	.05	.17	.03	–.02	.22	.20	.27	.26
ln(x5)	0	.33	.13	.34	.09	.37	.35	.26	.26
	1	–.35	–.12	–.15	–.33	.10	.04	.26	.26
	2	.03	.15	.04	–.05	.23	.32	.27	.26
ln(x6)	0	.44	.34	.36	.15	.36	.29	.26	.26
	1	–.34	.20	.01	–.15	.07	–.13	.26	.26
	2	.06	.27	.00	–.22	.17	.03	.27	.26
ln(x7)	0	.31	.17	.42	.16	.49	.41	.26	.26
	1	–.46	–.11	–.15	–.29	.13	.01	.26	.26
	2	.05	.18	.04	–.22	.31	.30	.27	.26
ln(x8)	0	.57	.39	.54	.22	.45	.43	.26	.26
	1	–.25	.16	–.03	–.25	.10	–.04	.26	.26
	2	.08	.34	.05	–.11	.23	.20	.27	.26
ln(x9)	0	–.28	–.11	–.34	–.26	–.20	–.34	.26	.26
	1	–.03	–.10	–.13	–.03	–.11	–.11	.26	.26
	2	–.09	–.11	.03	–.01	.04	–.02	.27	.26
ln(x11)	0	.47	.24	.31	.20	.25	.24	.26	.26
	1	–.14	.24	.11	–.06	.07	–.09	.26	.26
	2	–.09	.19	–.05	–.21	.07	–.07	.27	.26
ln(x12)	0	.34	.17	.49	.17	.52	.46	.26	.26
	1	–.41	–.14	–.12	–.26	.14	.05	.26	.26
	2	.12	.20	.03	–.01	.27	.31	.27	.26
ln(x13)	1	–.01	.14	–.05	–.20	.00	.02	.26	.26
	2	.18	.29	.13	.08	.12	.21	.27	.26
ln(x18)	0	.05	.11	.02	.09	–.03	.10	.26	.26
	1	.19	.10	.13	.30	.01	.12	.26	.26
	2	.21	–.08	.17	.30	.16	.24	.27	.26
observation *havaintoja*		59	58	58	58	58	58	58	59

Table 4. Estimated cross correlations between climatic factors and annual ring indices of Scots pine. See page 9 for the symbols of variables.

Taulukko. 4. Ilmastotietojen ja männyn vuosilustoindeksien välisten ristikorrelaatioiden estimaatteja. Muuttujaluettelo sivulla 9.

variable *muuttuja*	lag *viive*	index series – *indeksisarja*							2 S.E. ($r_{xy}(k)$)	
	k	Ruotsinkylä	Karvia	Koli 1	Koli 2 r_{xy} (k)	Punkaharju	Hyytiälä	Pallasjärvi		
xl	0	.03	.15	.13	.20	.15	.01	.01	.26	.24
	1	–.13	–.03	–.02	.12	.08	–.04	–.10	.26	.24
	2	.01	.10	.02	.14	.20	.08	–.11	.27	.24
ln(x2)	0	–.16	–.11	.01	–.05	–.05	–.09	.07	.26	.24
	1	–.02	.01	.10	.03	.04	.04	.12	.26	.24
	2	–.15	.00	.00	.07	–.23	–.11	–.09	.27	.24
ln(x3)	0	–.26	–.26	–.10	–.12	–.11	–.13	.16	.26	.24
	1	–.16	–.11	.03	–.01	.01	.00	.17	.26	.24
	2	–.19	–.07	.05	.03	–.04	.08	–.08	.27	.24
ln(x4)	0	.17	.04	.02	–.04	.16	.22	.53	.26	.24
	1	–.04	.01	–.18	–.16	–.10	–.17	.08	.26	.24
	2	–.05	.03	–.15	–.04	–.08	.00	.06	.27	.24
ln(x5)	0	.12	.01	.10	–.09	.05	.15	.25	.26	.24
	1	–.18	–.16	–.31	–.41	–.27	–.31	–.03	.26	.24
	2	–.03	–.07	–.17	–.20	–.21	–.07	.03	.27	.24
ln(x6)	0	–.06	–.16	–.06	–.12	.02	.05	.45	.26	.24
	1	–.14	–.07	–.10	–.10	–.05	–.10	.17	.26	.24
	2	–.16	–.03	–.08	–.02	–.07	.07	.00	.27	.24
ln(x7)	0	.16	.03	.05	–.06	.14	.22	.50	.26	.24
	1	–.10	–.05	–.26	–.27	–.17	–.24	.06	.26	.24
	2	–.05	.00	–.18	–.11	–.14	–.02	.06	.27	.24
ln(x8)	0	.00	–.09	.06	–.02	.11	.06	.41	.26	.24
	1	–.18	–.08	–.12	–.13	–.06	–.17	.14	.26	.24
	2	–.17	–.06	–.09	.02	–.15	.00	–.09	.27	.24
ln(x9)	0	.04	.00	–.04	–.06	.06	.02	–.11	.26	.24
	1	.04	–.03	–.04	–.24	–.03	–.02	–.12	.26	.24
	2	.02	–.10	.00	–.06	–.07	.00	.23	.27	.24
ln(x11)	0	–.24	–.27	–.04	–.07	–.13	–.08	.27	.26	.24
	1	–.15	–.10	.04	.02	.03	.01	.18	.26	.24
	2	–.24	–.08	.01	.07	–.08	.01	–.14	.27	.24
ln(x12)	0	.20	.06	.06	–.07	.16	.19	.46	.26	.24
	1	–.13	–.04	–.28	–.30	–.17	–.25	.04	.26	.24
	2	–.03	.06	.05	–.10	–.16	.00	–.18	.27	.24
ln(x13)	1	–.10	–.05	–.07	–.05	.04	–.12	.05	.26	.24
	2	–.11	–.10	–.03	.03	–.04	–.05	–.09	.27	.24
ln(x14)	0	.41	.41	.20	.24	.14	.13	.05	.26	.24
	1	.32	.04	.01	.19	.15	–.05	–.10	.26	.24
	2	.18	–.06	–.04	.05	.12	.03	–.08	.27	.24
ln(x15)	0	.27	.55	.34	.47	.26	.31	.03	.26	.24
	1	.32	.47	.30	.44	.24	.25	–.02	.26	.24
	2	.23	.14	–.03	.19	.22	.11	–.03	.27	.24
ln(x16)	0	.10	.19	.03	.00	.03	–.05	–.19	.26	.24
	1	.03	.08	.34	.18	.25	–.17	–.06	.26	.24
	2	.07	–.17	.11	.01	.04	–.01	–.01	.27	.24
ln(x17)	0	.24	–.07	.00	–.08	–.11	.05	–.12	.26	.24
	1	.34	.10	.23	.16	.00	.14	–.03	.26	.24
	2	.19	–.10	.11	.05	–.05	–.15	–.06	.27	.24
ln(x18)	0	.40	.58	.33	.38	.31	.21	–.12	.26	.24
	1	.29	.33	.39	.43	.40	.00	–.06	.26	.24
	2	.21	.04	–.04	.09	.22	.11	–.02	.27	.24
observations *havaintoja*		58	58	58	58	58	58	69	58	69

Table 5. Parameter estimates, residual standard deviations (s) and ceofficients of determination (R^2) for the model (42.1) in Norway spruce material. The t ratios for parameter estimates in parenthesis. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n for each series in Table 3.)

Taulukko 5. Mallin (42.1) parametrien estimaatit, jäännösten hajonnat (s) ja selitysasteet (R^2) kuusen paikallisille vuosilustoindekseille. Parametrien estimaattien t-arvot suluissa. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n eri sarjoille taulukossa 3.)

index series		variable – *muuttuja*		s	R^2
indeksisarja	$\ln(X8_t)$	$\ln(X18_t)$	$\ln(Y_{t-1})$		
Kuru – Ruovesi	.543 (5.74)	.082 (1.94)		.090	.360
Ruotsinkylä	.719 (3.50)	.104 (1.57)		.151	.190
	.405 (2.23)	.101 (1.83)	.554 (5.28)	.125	.460
Simpele	.753 (5.27)	.125 (2.28)		.113	.360
	.773 (6.03)	.136 (2.81)	.358 (3.74)	.100	.515
Koli	.235 (1.72)	.049 (0.77)		.142	.061
	.354 (3.15)	.032 (0.63)	.584 (5.51)	.115	.410
Hyytiälä	.612 (3.75)	.011 (0.19)		.137	.197
	.451 (3.41)	.080 (1.72)	.631 (6.34)	.107	.546
Parkano	.508 (3.71)	.048 (1.13)		.118	.185
	.422 (3.60)	.071 (1.98)	.533 (5.28)	.098	.470

Table 6. Parameter estimates, residual standard deviations (s) and coefficients of determination (R^2) for the model (42.2) in Norway spruce material. The t ratios for parameter estimates in parenthesis. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n for each series in Table 3.)

Taulukko 6. Mallin (42.2) parametrien estimaatit, jäännösten hajonnat (s) ja selitysasteet (R^2) kuusen paikallisille vuosilustoindekseille. Parametrien estimaattien t-arvot suluissa. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n eri sarjoille taulukossa 3.)

index series			variable – muuttuja			s	R^2
indeksisarja	$\ln(X8_t)$	$\ln(X18_t)$	$\ln(X7_{t-1})$	$\ln(X18_{t-1})$	$\ln(Y_{t-1})$		
Kuru–Ruovesi	.537 (6.43)	.107 (2.96)	–.308 (3.65)	.089 (2.47)		.076	.569
Ruotsinkylä	.693 (3.26)	.094 (1.37)	–.097 (0.53)	.046 (0.68)		.153	.208
	.359 (1.99)	.099 (1.80)	–.303 (1.99)	–.007 (.013)	.602 (5.62)	.123	.500
Simpele	.781 (5.47)	.088 (1.55)	.033 (0.23)	.096 (1.62)		.109	.433
	.719 (5.59)	.123 (2.38)	–.266 (1.81)	.006 (.106)	.441 (3.91)	.098	.552
Koli	.236 (1.80)	.042 (0.68)	–.258 (1.93)	.113 (1.83)		.134	.216
	.350 (3.58)	.029 (0.65)	–.397 (3.94)	.074 (1.61)	.638 (6.83)	.098	.581
Hyytiälä	.640 (3.77)	.009 (0.14)	.186 (1.22)	.040 (0.66)		.139	.225
	.421 (3.18)	.084 (1.80)	–.251 (1.89)	.009 (0.20)	.737 (6.50)	.105	.577
Parkano	.513 (3.60)	.044 (1.03)	.042 (0.33)	.057 (1.29)		.119	.213
	.405 (3.50)	.073 (2.09)	–.266 (1.98)	.017 (0.48)	.613 (5.60)	.096	.515

Table 7. Parameter estimates, residual standard deviations (s) and coefficients of determination (R^2) for the model (42.3) in Norway spruce material. The t ratios for parameter estimates in parenthesis. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n for each series in Table 3.)

Taulukko 7. Mallin (42.3) parametrien estimaatit, jäännösten hajonnat (s) ja selitysasteet (R^2) kuusen paikallisille vuosilustoindekseille. Parametrien estimaattien t-arvot suluissa. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n eri sarjoille taulukossa 3.)

index series			variable – muuttuja				s	R^2
indeksisarja	$\ln(X11_t)$	$\ln(X12_t)$	$\ln(X18_t)$	$\ln(X12_{t-1})$	$\ln(X18_{t-1})$	$\ln(Y_{t-1})$		
Kuru–Ruovesi	.231 (3.79)	.210 (2.33)	.123 (3.00)	–.271 (3.29)	.100 (2.53)		.084	.4.83
Ruotsinkylä	.272 (2.03)	.215 (1.26)	.085 (1.18)	–.105 (0.61)	.039 (0.55)		.160	.156
	.089 (0.90)	.129 (0.97)	.093 (1.66)	–.343 (2.54)	–.022 (0.38)	.646 (6.16)	.124	.499
Simpele	.228 (2.82)	.548 (4.62)	.126 (2.17)	.032 (0.27)	.093 (1.60)		.108	.457
	.189 (2.59)	.502 (4.70)	.153 (2.92)	–.258 (1.97)	.011 (0.19)	.450 (3.84)	.097	.568
Koli	.129 (1.78)	.143 (1.14)	.051 (0.84)	–.269 (2.14)	.121 (1.98)		.132	.249
	.173 (3.38)	.225 (2.55)	.043 (1.01)	–.410 (4.54)	.084 (1.96)	.657 (7.44)	.093	.635
Hyytiälä	.141 (1.49)	.544 (4.08)	.023 (0.40)	.128 (0.96)	.029 (0.50)		.132	.310
	.126 (1.71)	.317 (2.90)	.092 (2.01)	–.248 (2.07)	.007 (0.17)	.710 (6.09)	.102	.605
Parkano	.034 (0.37)	.436 (3.47)	.032 (0.74)	.020 (0.15)	.050 (1.11)		.120	.212
	.132 (2.02)	.275 (2.75)	.082 (2.33)	–.215 (2.00)	.026 (0.71)	.593 (5.06)	.095	.533

Table 8. Parameter estimates, residual standard deviations (s) and coefficients of determination (R^2) for the model (42.3) in Scots pine material. The t ratios for parameter estimates in parenthesis. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n for each series in Table 3.)

Taulukko 8. Mallin (42.3) parametrien estimaatit, jäännösten hajonnat (s) ja selitysasteet (R^2) männyn paikallisille vuosilustoindekseille. Parametrien estimaattien t-arvot suluissa. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, $i=1,\ldots, 18$, $j=1,\ldots,n$ (n eri sarjoille taulukossa 4.)

index series			variable – muuttuja				s	R^2
indeksisarja	$\ln(X11_t)$	$\ln(X12_t)$	$\ln(X18_t)$	$\ln(X12_{t-1})$	$\ln(X18_{t-1})$	$\ln(Y_{t-1})$		
Ruotsinkylä	–.206 (1.87)	.385 (2.56)	.203 (3.20)	–.110 (0.73)	.082 (1.30)		.141	.325
	–.141 (1.46)	.335 (2.56)	.149 (2.63)	–.298 (2.17)	–.022 (0.36)	.505 (4.22)	.122	.502
Karvia	–.175 (2.15)	.257 (2.17)	.244 (5.27)	–.089 (0.10)	.113 (2.41)		.123	.484
	–.158 (2.02)	.237 (2.08)	.213 (4.59)	–.119 (1.11)	.038 (0.69)	.299 (2.38)	.118	.536
Koli 1	.003 (0.05)	.096 (0.46)	.171 (2.76)	–.309 (2.41)	.159 (3.23)		.135	.324
	–.014 (0.23)	.294 (2.75)	.206 (4.15)	–.395 (3.85)	.044 (0.82)	.563 (5.57)	.107	.583
Koli 2	.013 (0.17)	–.063 (0.46)	.228 (3.33)	–.385 (2.77)	.218 (3.23)		.146	.419
	.019 (0.31)	.158 (1.41)	.257 (4.96)	–.405 (3.79)	.074 (1.31)	.543 (6.08)	.112	.666
Punkaharju	–.080 (0.62)	.244 (1.50)	.154 (1.72)	–.143 (0.87)	.197 (2.18)		.165	.246
	–.134 (1.42)	.364 (3.06)	.163 (2.52)	–.351 (2.88)	.026 (0.38)	.661 (6.91)	.119	.614
Hyytiälä	–.064 (0.68)	.261 (1.97)	.085 (1.51)	–.300 (2.28)	–.032 (0.56)		.131	.168
	–.022 (0.24)	.271 (2.14)	.105 (1.91)	–.352 (2.75)	–.061 (1.09)	.310 (2.34)	.126	.250
Pallasjärvi	.086 (1.60)	.371 (3.58)	.046 (0.46)	–.045 (0.86)	.036 (0.68)		.153	.263
	.115 (2.89)	.262 (3.38)	–.194 (2.38)	–.052 (1.36)	.039 (0.99)	.695 (7.37)	.112	.610

Table 9. Parameter estimates, residual standard deviations (s) and coefficients of determination (R^2) for the model (42.4) in Scots pine material. The t ratios for parameter estimates in parenthesis. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, i=1,..., 18, j=1,...,n (n for each series in Table 4.)

Taulukko 9. Mallin (42.4) parametrien estimaatit, jäännösten hajonnat (s) ja selitysasteet (R^2) männyn paikallisille vuosilustoindekseille. Parametrien estimaattien t-arvot suluissa. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, i=1,..., 18, j=1,...,n (n eri sarjoille taulukossa 4.)

index series		variable – *muuttuja*		s	R^2
indeksisarja	$\ln(X12_t)$	$\ln(X18_t)$	$\ln(Y_{t-1})$		
Ruotsinkylä	.348 (2.29)	.238 (3.73)		.145	.236
	.303 (2.27)	.166 (2.86)	.461 (4.25)	.127	.430
Karvia	.112 (0.95)	.268 (5.36)		.135	.349
	.121 (1.14)	.217 (4.61)	.383 (3.70)	.121	.483
Koli 1	.101 (0.74)	.189 (2.84)		.148	.131
	.269 (2.32)	.201 (3.70)	.561 (5.37)	.120	.437
Koli 2	–.051 (0.33)	.254 (3.33)		.169	.179
	.169 (1.38)	.256 (4.49)	.601 (6.55)	.127	.546
Hyytiälä	.215 (1.63)	.090 (1.58)		.134	.079
	.227 (1.75)	.100 (1.78)	.227 (1.75)	.130	.130
Punkaharju	.292 (1.78)	.238 (2.76)		.171	.146
	.363 (2.96)	.204 (3.16)	.623 (6.62)	.128	.533
Pallasjärvi	.394 (4.16)	–.027 (0.59)		.154	.219
	.293 (3.69)	–.060 (1.56)	.551 (5.78)	.126	.487

Table 10. Parameter estimates, residual standard deviations (s) and coefficients of determination (R^2) for the model (42.5) in Scots pine material. The t ratios for parameter estimates in parenthesis. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, i=1,..., 18, j=1,...,n (n for each series in Table 4.)

Taulukko 10. Mallin (42.5) parametrien estimaatit, jäännösten hajonnat (s) ja selitysasteet (R^2) männyn paikallisille vuosilustoindekseille. Parametrien estimaattien t-arvot suluissa. $X_{ij} = (100\ x_{ij} / \bar{x}_i)$, i=1,..., 18, j=1,...,n (n eri sarjoille taulukossa 4.)

index series			variable – muuttuja			s	R^2
indeksisarja	$\ln(X12_t)$	$\ln(X18_t)$	$\ln(X12_{t-1})$	$\ln(X18_{t-1})$	$\ln(Y_{t-1})$		
Ruotsinkylä	.330 (2.18)	.214 (3.30)	–.109 (0.71)	.094 (1.45)		.144	.278
	.296 (2.28)	.153 (2.68)	–.308 (2.22)	–.020 (0.32)	.533 (4.46)	.123	.481
Karvia	.160 (1.41)	.258 (5.42)	–.053 (0.46)	.132 (2.77)		.128	.437
	.148 (1.37)	.222 (4.68)	–.089 (0.81)	.049 (0.87)	.322 (2.50)	.122	.499
Koli 1	.097 (0.78)	.171 (2.79)	–.308 (2.44)	.159 (2.60)		.133	.324
	.290 (2.77)	.206 (4.20)	–.396 (3.89)	.044 (0.83)	.562 (5.61)	.106	.582
Koli 2	–.060 (0.44)	.227 (3.41)	–.385 (2.79)	.218 (3.26)		.145	.418
	.164 (1.49)	.256 (5.00)	–.404 (3.82)	.074 (1.32)	.542 (6.13)	.111	.665
Hyytiälä	.244 (1.89)	.088 (1.57)	–.290 (2.23)	–.025 (0.45)		.131	.160
	.266 (2.16)	.106 (1.96)	–.350 (2.76)	–.060 (1.08)	.316 (2.45)	.125	.249
Punkaharju	.227 (1.42)	.159 (1.79)	–.128 (0.79)	.205 (2.30)		.164	.241
	.333 (2.82)	.171 (2.63)	–.322 (2.82)	.042 (0.60)	.649 (6.75)	.120	.599
Pallasjärvi	.421 (4.21)	–.050 (0.95)	.027 (0.27)	.055 (1.03)		.155	.232
	.332 (4.28)	–.059 (1.45)	–.210 (2.44)	.063 (1.55)	.668 (6.73)	.119	.556

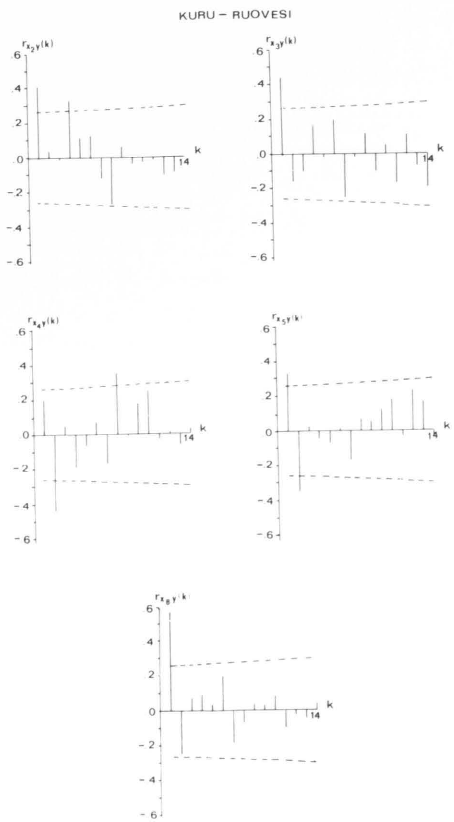


Figure 10. The estimated cross correlations versus the lag k (k=0, . . . ,14) between the logarithms of the effective temperature sums and the Kuru – Ruovesi spruce series of Mikola (1950). (-----) = 2S.E.($r_{xy}(k)$).

Kuva 10. Lämpösummatunnusten ja Mikolan (1950) Kurun – Ruoveden kuusen indeksisarjan logaritmien välisten ristikorrelaatioiden estimaatteja viiveen k arvoilla 0, . . . ,14. (-----) = 2S.E.($r_{xy}(k)$).

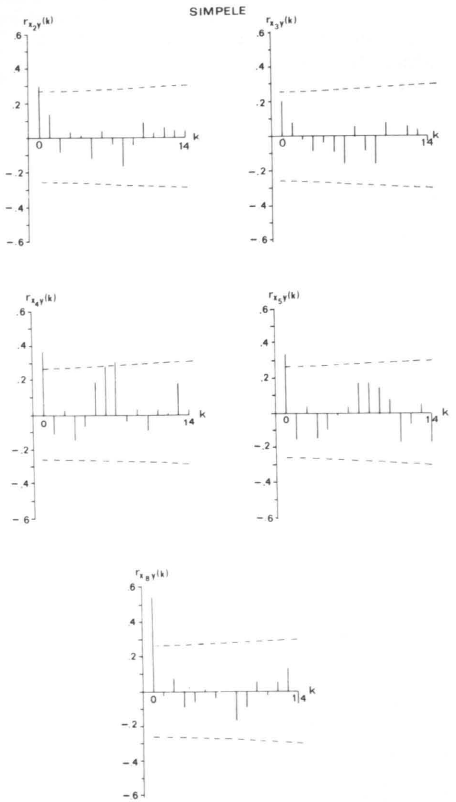


Figure 11. The estimated cross correlations versus the lag k (k=0, . . . ,14) between the logarithms of the effective temperature sums and the Simpele spruce series of Thammincha (1981) (-----) = 2S.E.($r_{xy}(k)$).

Kuva 11. Lämpösummatunnusten ja Thamminchan (1981) Simpeleen kuusen indeksisarjan logaritmien välisten ristikorrelaatioiden estimaatteja viiveen k arvoilla 0, . . . ,14. (-----) = 2S.E.($r_{xy}(k)$).

1959) and the 6th (Tiihonen 1979) National Forest Inventory.

The correlations between the estimated and actual indices were as follows:

years 1916–1935

	Ilves-salo	Tham-mincha	Test material
Model (42.2)	.78	.75	.84
Model (42.3)	.76	.70	.79

years 1936–1959

	Ilves-salo	Tham-mincha	Test material	Tii-honen
Model (42.2)	.34	.56	.53	.57
Model (42.3)	.42	.57	.55	.59

years 1960–1972

	Tham-mincha	Test material	Tii-honen
Model (42.2)	.30	.24	.30
Model (42.3)	.11	.04	.26

The correlation between the estimated and actual indices decreases from the 1950's, after which the estimated indices are clearly overestimates (Fig. 9).

422. Transfer function models

Due to the problems caused by the autocorrelation of residuals and difficulties of interpreting parameter estimates, a transfer function model was identified and estimated for each annual ring index series.

For the Norway spruce series the models were first fitted with the effective temperature sum (variable X8) as the only input series. The estimated cross correlation functions between the logarithms of the effective temperature sum and the annual ring indices of spruce are presented in Figs. 10, 11 and 12. In one part of the material there were, however, significant cross correlations between the precipitation sum during May – July and the estimated residuals of the models. Consequently, two models were fitted using the precipitation sum (variable X18) as the second input series. The prewhitening of input was not necessary, since the input processes were white noise. Neither the estimated cross correlations between the used input series were significant. The correlations between the input series were low because the temperature and precipitation sums were integrated over long and partly separate periods of growing season.

The final transfer function – noise models for the index series of Norway spruce were as follows (The t ratios for parameter estimates are in parenthesis, critical values with 50 degrees of freedom (f) are

$t(.05/2)=2.01$, $t(.01/2)=2.68$, $t(.001/2)=3.49$):

KURU – RUOVESI

$$\ln(Y_t)= (\omega_{10}+\omega_{11}B)\ln(X8_t)+\frac{\omega_{20}}{(1-\delta_{21}B)}\ln(X18_t)+a_t$$

$\hat{\omega}_{10}= .569\ (6.35)$ $s_a=.083$ $R^2=.484$
$\hat{\omega}_{11}=-.206\ (2.40)$ $f=54$
$\hat{\omega}_{20}= .125\ (3.08)$ $BX_t= X_{t-1}$, $B^bX_t=X_{t-b}$
$\hat{\delta}_{21}= .468\ (2.06)$

RUOTSINKYLÄ

$$\ln(Y_t)= \frac{(\omega_{10}+\omega_{11}B+\omega_{12}B^2)}{(1-\delta_{11}B)}\ln(X8_t) + \frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}= .375\ (2.09)$ $s_a=.121$ $R^2=.532$
$\hat{\omega}_{11}=-.036\ (\ .18)$ $f=52$
$\hat{\omega}_{12}= .432\ (2.61)$
$\hat{\delta}_{11}= .356\ (\ .99)$
$\hat{\phi}_1= .585\ (4.53)$

SIMPELE

$$\ln(Y_t)=\omega_{10}\ln(X8_t)+\frac{\omega_{20}}{(1-\delta_{21}B)}\ln(X18_t)$$
$$+\frac{1}{(1-\phi_1 B-\phi_2 B^2)}a_t$$

$\hat{\omega}_{10}= .679\ (6.30)$ $s_a=.096$ $R^2=.583$
$\hat{\omega}_{20}= .140\ (3.39)$ $f=52$
$\hat{\delta}_{21}= .664\ (3.37)$
$\hat{\phi}_1= .383\ (2.96)$
$\hat{\phi}_2= .242\ (1.87)$

KOLI

$$\ln(Y_t)=(\omega_{10}+\omega_{11}B)\ln(X8_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}= .416\ (4.79)$ $s_a=.093$ $R^2=.625$
$\hat{\omega}_{11}=-.183\ (2.05)$ $f=54$
$\hat{\phi}_1= .763\ (8.37)$

HYYTIÄLÄ

$$\ln(Y_t)=(\omega_{10}+\omega_{11}B+\omega_{12}B^2)\ln(X8_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}= .435\ (3.48)$ $s_a=.102$ $R^2=.594$
$\hat{\omega}_{11}=-.018\ (\ .13)$ $f=53$
$\hat{\omega}_{12}= .207\ (1.73)$
$\hat{\phi}_1= .691\ (6.68)$

PARKANO

$$\ln(Y_t)= \frac{(\omega_{10}+\omega_{11}B+\omega_{12}B^2)}{(1-\delta_{11}B)}\ln(X8_t) + \frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}= .408\ (3.79)$ $s_a=.087$ $R^2=.602$
$\hat{\omega}_{11}=-.365\ (2.20)$ $f=52$
$\hat{\omega}_{12}= .321\ (2.66)$
$\hat{\delta}_{11}= .601\ (1.66)$
$\hat{\phi}_1= .669\ (6.68)$

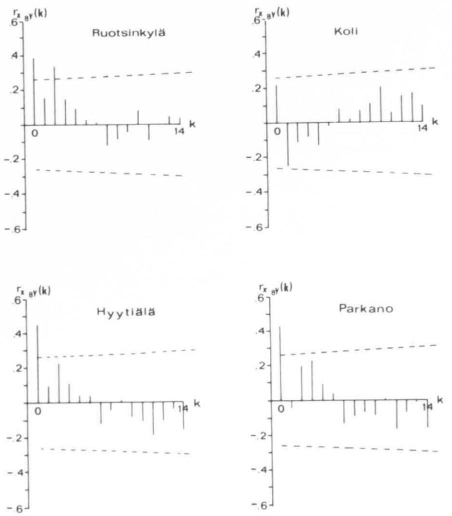


Figure 12. The estimated cross correlations versus the lag k (k=0, . . . ,14) between the logarithms of the effective temperature sum during the whole vegetation period and the spruce index series. (-----) = 2S.E.($r_{xy}(k)$).

Kuva 12. Kasvukauden lämpösumman ja kuusen vuosilustoindeksisarjojen logaritmien välisten ristikorrelaatioiden estimaatteja viiveen k arvoilla 0, . . . ,14. (-----) = 2S.E.($r_{xy}(k)$).

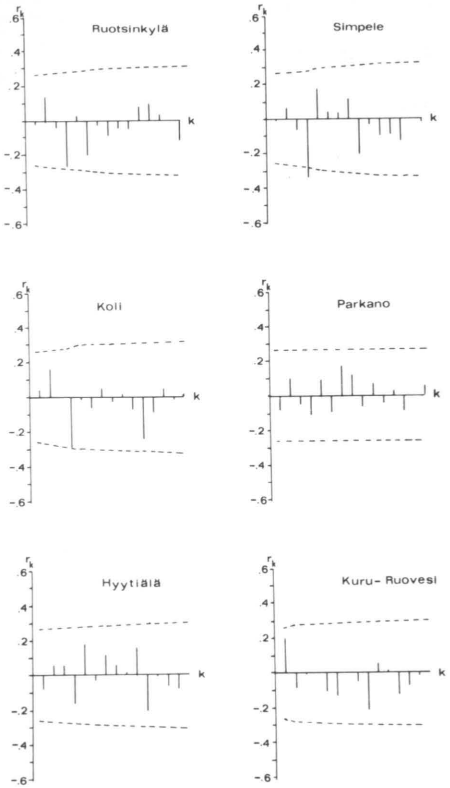


Figure 13. The estimated autocorrelations versus the lag k (k=1, . . . ,15) for the residuals {$\hat{a}_t$} of the fitted transfer function – noise models for the Norway spruce indices. (-----) = 2S.E.(r_k).

Kuva 13. Kuusen indeksisarjojen siirtofunktio-kohinamallien jäännösten {$\hat{a}_t$} autokorrelaatioiden estimaatteja viiveen k arvolla 1–15. (-----) = 2S.E.(r_k).

The estimated cross correlation functions between input series and residuals {$\hat{a}_t$} are presented in Table 11. The estimated autocorrelation functions for the residuals are illustrated in Fig. 13. In the models given above the correlation coefficients between parameter estimates were all less than 0.5.

The most important factor affecting the variation in radial growth was the effective temperature sum of the growing season. The effective temperature sum during the previous year had significantly negative influence on radial increment in three series. In the series of Kuru-Ruovesi and Simpele the precipitation during May – July also appeared to have a positive effect.

The effective temperature sum during the latter part of the growing season (variable X12) and precipitation sum during May – July (variable X18) were taken as input series for the Scots pine models. The mean temperature of April was also tested instead of X12 but it proved to be insignificant in every series. The final models were as follows (The t ratios for parameter estimates are in parenthesis, critical values with 50 degrees of freedom (f) are t(.05/2)=2.01, t(.01/ 2)=2.68, t(.001/ 2)=3.49):

RUOTSINKYLÄ

$$\ln(Y_t)=\omega_{10}\ln(X12_t)+\frac{\omega_{20}}{(1-\delta_{21}B)}\ln(X18_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}=.355$ (3.09) $s_a=.122$ $R^2=.470$
$\hat{\omega}_{20}=.158$ (2.82) $f=54$
$\hat{\delta}_{21}=.493$ (1.73) $BX_t=X_{t-1}$, $B^bX_t=X_{t-b}$
$\hat{\phi}_1=.524$ (4.26)

KARVIA

$$\ln(Y_t)=\frac{\omega_{20}}{(1-\delta_{21}B)}\ln(X18_t)+\frac{1}{(1-\phi_1 B-\phi_2 B^2)}a_t$$

$\hat{\omega}_{20}=.220$ (5.19) $s_a=.118$ $R^2=.515$
$\hat{\delta}_{21}=.413$ (2.34) $f=53$
$\hat{\phi}_1=.220$ (1.56)
$\hat{\phi}_2=.273$ (1.91)

KOLI 1

$$\ln(Y_t)=\omega_{10}\ln(X12_t)+(\omega_{20}+\omega_{21}B)\ln(X18_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}=.408$ (5.12) $s_a=.100$ $R^2=.615$
$\hat{\omega}_{20}=.192$ (4.58) $f=53$
$\hat{\omega}_{21}=.182$ (4.44)
$\hat{\phi}_1=.737$ (7.84)

KOLI 2

$$\ln(Y_t)=(\omega_{10}+\omega_{11}B)\ln(X12_t)+(\omega_{20}+\omega_{21}B)\ln(X18_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}=.231$ (2.27) $s_a=.110$ $R^2=.671$
$\hat{\omega}_{11}=-.229$ (2.24) $f=52$
$\hat{\omega}_{20}=.226$ (4.85)
$\hat{\omega}_{21}=.172$ (3.72)
$\hat{\phi}_1=.698$ (6.64)

PUNKAHARJU

$$\ln(Y_t)=\omega_{10}\ln(X12_t)+(\omega_{20}+\omega_{21}B)\ln(X18_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}=.374$ (3.90) $s_a=.122$ $R^2=.582$
$\hat{\omega}_{20}=.133$ (2.18) $f=53$
$\hat{\omega}_{21}=.121$ (2.00)
$\hat{\phi}_1=.695$ (6.95)

HYYTIÄLÄ

$$\ln(Y_t)=(\omega_{10}+\omega_{11}B)\ln(X12_t)+\omega_{20}\ln(X18_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{10}=.274$ (2.27) $s_a=.122$ $R^2=.341$
$\hat{\omega}_{11}=-.275$ (2.27) $f=53$
$\hat{\omega}_{20}=.115$ (2.22)
$\hat{\phi}_1=.368$ (2.71)

PALLASJÄRVI

$$\ln(Y_t)=\omega_{30}\ln(X11_t)+\omega_{20}\ln(X12_t)+\frac{1}{(1-\phi_1 B)}a_t$$

$\hat{\omega}_{30}=.076$ (2.24) $s_a=.114$ $R^2=.501$
$\hat{\omega}_{20}=.301$ (4.77) $f=65$
$\hat{\phi}_1=.662$ (6.94)

The estimated cross correlations between input series and residuals $\{\hat{a}_t\}$ are presented in Table 12 and the estimated residual autocorrelations in Figs. 15 and 16. The highest correlation coefficient between parameter estimates was 0.45 between $\hat{\omega}_{10}$ and $\hat{\omega}_{11}$ in the model for Koli 2 series.

In the models fitted for Scots pine annual ring index series the influence of the effective temperature sum appeared to be greater than in regression models presented in Tables 8...10. The effective temperature sum of the latter part of the growing season was, excluding the Karvia series, a singnificant variable. Also in the Ruotsinkylä, Koli 1, Punkaharju, Hyytiälä and Pallasjärvi series it was the most important climatic factor employed.

Table 11. The estimated cross correlations between the input series and residuals $\{\hat{a}_t\}$ of the fitted transfer function – noise models for Norway spruce.

Taulukko 11. Kuusen siirtofunktio-kohinamallien selittävien muuttujien ja jäännösten $\{\hat{a}_t\}$ välisten ristikorrelaatioiden estimaatit.

variable *muuttuja*	lag *viive* k	index series – *indeksisarja* Kuru	 Ruotsinkylä	 Simpele	$r_{x\hat{a}}(k)$ Koli	 Hyytiälä	 Parkano	2 S.E. ($r_{x\hat{a}}(k)$)	
ln(X8)	0	.00	.00	.02	–.04	.02	.03	.26	.26
	1	.02	.00	.01	–.06	.03	.03	.26	.26
	2	.13	.00	.06	–.07	.04	.00	.27	.26
	3	.07	–.04	–.16	.00	.06	.09	.27	.27
	4	–.04	.09	.03	–.04	–.02	–.02	.27	.27
	5	.26	.00	.13	.15	.02	–.01	.27	.27
	6	–.16	–.10	–.06	.18	–.25	–.26	.28	.27
	7	–.15	–.13	.00	–.06	.08	.00	.28	.28
	8	.03	.02	–.11	.17	.09	.05	.28	.28
	9	.19	.02	.02	.11	–.11	.05	.29	.28
	10	.08	.12	.05	.07	–.12	–.05	.29	.29
	11	–.14	–.02	–.02	.04	–.10	.03	.29	.29
	12	.00	.02	–.10	–.04	–.11	–.09	.29	.29
	13	–.07	.04	–.03	.05	.02	–.12	.30	.29
	14	.01	.04	–.05	.08	–.12	.03	.30	.30
ln(X18)	0	–.06		.00				.26	.26
	1	.18		.00				.26	.26
	2	.05		.12				.27	.26
	3	–.04		.07				.27	.27
	4	–.31		–.18				.27	.27
	5	–.18		–.27				.27	.27
	6	–.05		–.26				.28	.27
	7	–.02		–.10				.28	.28
	8	–.18		.19				.28	.28
	9	–.14		.30				.29	.28
	10	–.05		.27				.29	.29
	11	–.02		.04				.29	.29
	12	.02		–.13				.29	.29
	13	–.03		–.11				.30	.29
	14	.03		–.09				.30	.30
observations *havaintoja*		59	58	58	58	58	58	58	59

Table 12. The estimated cross correlations between the input series and residuals $\{\hat{a}_t\}$ of the fitted transfer function – noise models for Scots pine.

Taulukko 12. Männyn siirtofunktio-kohinamallien selittävien muuttujin ja jäännösten $\{\hat{a}_t\}$ välisten ristikorrelaatioiden estimaatit.

variable *muuttuja*	lag *viive* k	index series – *indeksisarja*							2 S.E. ($r_{x\hat{a}}$ (k))	
		Ruotsinkylä	Karvia	Koli 1	Koli 2 $r_{x\hat{a}}$ (k)	Punkaharju	Hyytiälä	Pallasjärvi		
ln(X12)	0	–.06		–.08	.01	–.05	.01	–.02	.26	.24
	1	–.12		–.11	.01	–.07	.01	–.03	.26	.24
	2	.05		.03	.02	–.03	.04	.07	.27	.24
	3	–.10		–.01	–.04	.05	–.20	.08	.27	.25
	4	.19		.26	.14	.09	.05	–.20	.27	.25
	5	–.04		.07	.20	–.04	–.10	–.18	.27	.25
	6	–.16		–.02	.04	–.34	–.32	–.06	.28	.25
	7	.19		.18	.14	.31	.07	.10	.28	.25
	8	.06		.17	.23	.12	.14	–.18	.28	.26
	9	.04		.14	.14	–.01	.10	–.03	.29	.26
	10	–.02		.06	.05	.10	–.24	.12	.29	.26
	11	.05		–.12	–.10	–.04	–.06	–.21	.29	.26
	12	.03		–.17	–.08	.02	–.04	–.05	.29	.26
	13	–.07		–.01	.01	.21	.11	.01	.30	.27
	14	.00		–.06	–.03	.19	–.16	–.11	.30	.27
ln(X18)	0	.00	.01	–.01	.08	.00	.02		.26	.24
	1	–.01	–.03	–.01	.11	.07	–.05		.26	.24
	2	.01	.01	–.02	.15	.02	.10		.27	.24
	3	.10	.06	–.12	–.01	.07	.05		.27	.25
	4	–.09	–.04	–.13	–.10	–.13	–.02		.27	.25
	5	.04	.01	.18	–.01	.03	–.05		.27	.25
	6	–.14	–.29	.06	–.13	–.12	–.17		.28	.25
	7	.00	.02	.13	.02	–.18	–.06		.28	.25
	8	–.14	–.17	.00	–.09	–.24	–.42		.28	.26
	9	.10	–.08	–.04	–.02	.01	–.10		.29	.26
	10	–.01	.03	.09	.09	.08	.14		.29	.26
	11	.05	.11	–.15	.03	.05	–.08		.29	.26
	12	–.14	–.22	.07	.12	–.05	–.04		.29	.26
	13	.02	–.17	–.01	.00	.02	–.04		.30	.27
	14	.08	.20	.05	.07	.03	.30		.30	.27
ln(X11)	0							.12		.24
	1							.17		.24
	2							–.20		.24
	3							.07		.25
	4							.13		.25
	5							–.10		.25
	6							–.06		.25
	7							.11		.25
	8							–.15		.26
	9							–.25		.26
	10							.09		.26
	11							.01		.26
	12							.06		.26
	13							–.12		.27
	14							.11		.27
observation *havaintoja*		58	58	58	58	58	58	69	58	69

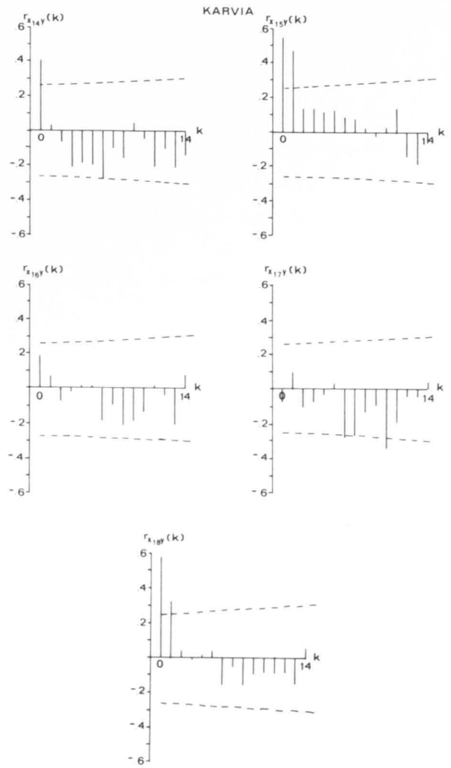


Figure 14. The estimated cross correlations versus the lag k (k=0, . . . ,14) between the logarithms of the precipitation sums and the Karvia pine index series. (-----) = 2S.E.(r_{xy}(k)).

Kuva 14. Sademäärien ja Thamminchan (1981) Karvian männyn vuosilustoindeksisarjan logaritmien välisten ristikorrelaatioiden estimaatteja viiveen k arvoilla 0–14. (-----) = 2S.E.(r_{xy}(k)).

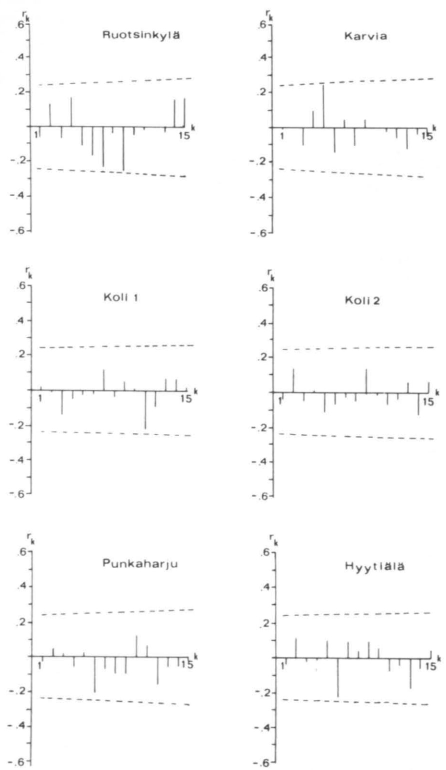


Figure 15. The estimated autocorrelations versus the lag k (k=l, . . . ,15) for the residuals $\{\hat{a}_t\}$ of the fitted transfer function – noise models for the Scots pine indices in southern Finlad. (-----) = 2S.E.(r_k).

Kuva 15. Etelä-Suomen männyn indeksisarjojen siirtofunktiokohinamallien jäännösten $\{\hat{a}_t\}$ autokorrelaatioiden estimaatteja viiveen k arvoilla 1–15. (-----) = 2S.E.(r_k).

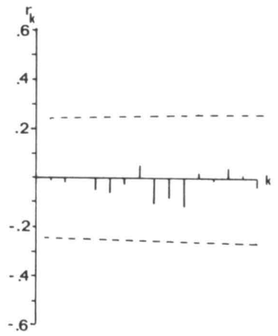


Figure 16. The estimated autocorrelations versus the lag k (k=l, . . . ,15) for the residuals $\{\hat{a}_t\}$ of transfer function – noise model fitted for the Pallasjärvi pine series. (-----) = 2S.E.(r_k).

Kuva 16. Pallasjärven männyn indeksisarjan siirtofunktiokohinamallin jäännösten $\{\hat{a}_t\}$ autokorrelaatioiden estimaatteja viiveen k arvolla 1–15. (-----) = 2S.E.(r_k).

5. DISCUSSION

51. Factors affecting the reliability of results

The study material was heterogenous. The sample trees of various ages represented different sites and also stands treated with thinnings and fertilization (Tables 1 and 2). Although there was information available about the years during which silvicultural measures had taken place, it was no longer possible to make any corrections in the material, because the changes in the level of radial increment have influenced on the form of the applied smoothing function and thus on every term of the index series.

The monthly precipitation sums, mean temperatures and effective temperature sums were derived from the measurements of the Meteorological Office. The standard error for the effective temperature sum of the growing season is about 50 d.d. For the precipitation sums of May, June and July the standard errors are 7, 12 and 17 mm respectively. The reliability of the climatic data is lower for the early years because of the more sparse grid of observation stations.

The heterogenity of the indices justifies only a rough analysis of the factors affecting growth. Thus the indices from different localities were processed separately.

52. The properties of annual ring index series

In the studied index series of Thammincha (1981) the autocorrelation coefficients at lag 1 varied from .39 to .63 for Norway spruce and from .35 to .62 for Scots pine. The result contradicts the observations of Ording (1941) and Eklund (1954) according to which there are no significant autocorrelations in the index series of spruce. On the other hand Jonsson (1969) found a significant positive correlation between sucessive terms of Norway spruce annual ring index series.

The differences in structures of indices from different localities and authors were noticeable. The Norway spruce indices of Thammincha (1981) constituted a relatively homogenous group having AR(1)– or AR(2)– structures while in the Kuru–Ruovesi spruce series of Mikola (1950) no significant autocorrelations were discernible. The Scots pine index series of Thammincha (1981) and of the Forest Research Institute comprised the supposed AR(1)– structures as well as cyclic variation and trends.

Correlation analysis was used to study the uniformity of radial increment variation. The correlation between prewhitened series was on average higher than the correlation between the original index series. This result corresponds to the results of Eklund (1954) and Brandt (1975). No difference could be found between the tree species. According to Ording (1941) and Ilvessalo (1945) the radial growth variation of pine is more uniform within large areas while the correlation of spruce indices located near each other is higher.

53. Climatic factors and annual ring indices

If it is suggested that large area growth variations are caused by climate, the inconsistency of local annual ring index series does not raise great expectations for models predicting the growth variations with climatic factors. If southern Finland is considered as a climatically homogenous area, the variance of indices explained by climatic factors is about equal to the variance of each index series explained by other series, i.e., about 20 %.

The commonly applied distributed lag models were unsatisfactory as regards the purposes of this study. The transfer function-noise models seemed to meet the requirements better. The final results correspond roughly to those of several former studies.

531. Norway spruce

The decisive factor for the annual ring variation of Norway spruce is the effective temperature sum of the growing season. This result is in contradiction to the results of Eklund (1957) according to which the temperature of the early part of summer is more important in northern Sweden. Jonsson (1969) reports that except Norrland the temperature of the present growing season has only a minor influence on the increment variation of Norway spruce.

According to the cross correlations, the temperature of the latter part of the previous summer had a negative effect on radial increment. The effective temperature sum of the latter part of the growing season was not, however, incorporated as an input series to the transfer function models because of its high correlation with the effective temperature sum of the whole growing season. The negative effect of the warm previous summer on the increment of Norway spruce has also been reported by Wallen (1917), Eklund (1957), Jonsson (1969), Feliksik (1972), and Eckstein and Aniol (1981). This result can be explained in two ways. First, the conditions during the latter part of the summer determine the amount of stored carbohydrates and promote the formation of shoot primordia, which affects the relation between shoot and diameter increment during the next growing season (Jonsson 1969, Cannel et al. 1976). Secondly, high temperatures promote the differentation of the flower buds (Lakari 1921, Leikola et al. 1982). Tiren (1935) found the promoting effect of high July temperature on the flowering during next summer. According to Brondbo (1970) the decisive period is June. Chałupka (1975) in Poland reports it to be June – July. In the present study the effect of seed crops could be incorporated to models only through climatic factors.

The precipitation sum of May-July had a growth-promoting influence on the radial growth in two of the studied series. Slåstad (1957) in southern Norway and Jonsson (1969) in Sweden have also found precipitation somewhat important. Eklund (1957) in northern Sweden reports that the precipitation during January – May has some influence on the radial increment of spruce. This variable was, however, not used in this study.

532. Scots pine

On the ground of correlation analysis the precipitation sum seemed to be more important for the growth variation of Scots pine in southern Finland than the effective temperature sum. In transfer function models the significance of the temperature of the latter part of summer increased. The temperature of April did not have any significant effect, which is in contradiction to the results of Laitakari (1920), Holmsgaard (1955) and Jonsson (1969). The high effective temperature sums during the latter part of the previous summer had a negative effect in two of the studied series. According to Jonsson (1969) this effect should occur later, after the middle of August.

The effect of the precipitation sum during May – July was significant in every studied series located in southern Finland and its significance was the greatest in the series of Karvia and Koli, which were located on the driest sites. In the series of Pallasjärvi precipitation had no significant effect on growth. This result, concerning the only studied series located in the northern Finland, is in accordance with the results of Hustich and Eleving (1945) from northern tree line and with studies from the alpine tree line (Bednarz 1981, Heikkinen 1980 etc.).

LITERATURE

Anderson, O. D. 1976. Time series analysis and forecasting. The Box-Jenkins approach. Butterworth.

Andersson, S.-O. 1953. Om tidpunkten för den årliga diametertillväxtens avslutande hos tall och gran. Medd. från statens skogsforskningsinst. 43(5).

Bednarz, Z. 1981. Relationship of tree-ring widths in the Tatra Mountains to variation in monthly mean temperature and precipitation. Mitt. Forstl. VersAnst. 142/II.

Boman, A. 1927. Männyn kasvun monivuotisista vaihteluista. Acta For. Fenn. 32(4).

Box, G. E. P. & Jenkins, G. M. 1976. Time series analysis, forecasting and control. Revised Edition. Holden-Day. San Francisco.

Brandt, N. 1975. Årringsundelsokelser på furu (*P. silvestris*). Metode og anvendelse. Medd. fra Norsk Institutt for Skogsforskning 32.7.

Bräker, O. 1981. Der Alterstrend bei Jahrringdichten und Jahrringbreiten von Nadelhölzern und sein Ausgleich. Mitt. Forstl. VersAnst. 142/I.

Brondbo, P. 1970. Meteorological factors, flowering intensity and cone crop of *Picea abies* in southeastern Norway. Proc. meeting IUFRO working group of sexual reproduction of forest trees, Varparanta, Finland. I/2.

Chałupka, W. 1975. Wplyw czynnikow klimatycznych na urodzaj szyszek u swierka pospolitego (*Picea abies* Karst.) w Polsce. English summary. Arboretum Kornickie. Rocznik XX.

— , Giertych, M. & Krolikowski, Z. 1975. The effect of cone crops on growth in Norway spruce (*Picea abies* Karst.). Arboretum Kornickie. Rocznik XX.

— , Giertych, M. & Krolikowski, Z. 1976. The effect of cone crops in Scots pine on tree diameter increment. Arboretum Kornickie. Rocznik XXI.

Douglass, A. E. 1919. Climatic cycles and tree growth. Carnegie Inst. Wash. Pub. No. 289. Washington.

Eckstein, B. & Aniol, R. W. 1981. Dendroclimatological reconstruction of the summer temperatures for an alpine region. Mitt. Forstl. VersAnst. 142/II.

Eide, E. 1926. Om sommarvarmens inflydelse på årringsbredden. Medd. Norsk skogforsoksvesen 2.

Eklund, B. 1944. Ett försök att numeriskt fastställa klimatets inflytande på tallens och granens tillväxt vid de båda finska riksskogstaxeringarna. Norrl. Skogsv. Förb. Tidskr.

— 1954. Årsringsbreddens klimatiskt betingade variation hos tall och gran inom norra Sverige åren 1900—1944. Medd. från statens skogsforskninginst. 44(8).

— 1957. Om granens årsringsvariationer inom mellersta Norrland och deras samband med klimatet. Medd. från statens skogsforskninginst. 47(1).

Feliksik, E. 1972. Studia dendroklimatologizne nad swierkiem (*Picea excelsa* L.). Engl. summary. Acta Agrar. Silv. (Ser. Silv.) 12.

Fritts, H. C. 1976. Tree rings and climate. Academic Press.

Heikkinen, O. 1980. Mountain pine radial growth and the forest limit zone in Gadmental, the Swiss Alps. Fennia 158.

Holmsgaard, E. 1955. Årsringsanalyser af danske skovstraeer. Forstl. Forsøgsv. Danm. 22(1).

Huber, B. & v. Jazewitsch, W. 1952. Aus der Praxis der Jahrring-Analyse. Allg. Forstzeitschrift.

Hustich, I. 1948. The Scots pine in northernmost Finland and its dependence on the climate in the last decades. Acta Bot. Fenn. 42.

— 1981. Some remarks on the climate/tree growth relationship in northern Europe. Mitt. Forstl. VersAnst. 142/II.

— & Elfving, G. 1944. Die Radialzuwachsvariationen der Waldgrenzkiefer. Soc. Scient. Fenn., Comm. Biol. 9(8).

Ilvessalo, Y. 1945. Puiden kasvun vaihtelu ja sen merkitys kasvututkimuksissa. Metsätal. Aikakl. 1.

— 1959. Suomen metsien hakkuumahdollisuudet metsävarojen kehittämiseen tähtäävän hakkuusuunnitteen valossa. Commun. Inst. For. Fenn. 51.9.

Jonsson, B. 1969. Studier över den av väderleken orsakade variationen i årsringsbredderna hos tall och gran i Sverige. Rapp. Uppsats. Instn. Skogsprod. Skogshögsk. 16.

— & Hägglund, B. 1979. Korrektion av uppmättägs diametertillväxter med hjälp av årsringindex – en specialstudie för projekt Hugin. Sveriges lantbruksuniversitet. Skogsvetenskapliga fakulteten. Rapport 11.

Klemmer, L. 1969. Die Periodik des Radialzuwachses in einem Fichtenwald und deren meteorologisches Steuerung. Wissenschaftliche Mitteilung 17, Universität München – Meteorologisches Institut.

Kärenlampi, L. 1972. On the relationships of the Scots pine annual ring width and some climatic variables at the Kevo Subarctic Station. Reports from the Kevo Subarctic Res. Sta. Rep. 9.

Laitakari, E. 1920. Tutkimuksia sääsuhteiden vaikutuksesta männyn pituus- ja paksuuskasvuun. Acta For. Fenn. 17.

Lakari, O. 1921. Tutkimuksia kuusimetsien uudistumisvuosista Etelä- ja Keski-Suomessa. Metsätieteellisen koelaitoksen julkaisuja 4.

LaMarche, V. C. 1974. Paleoclimatic inferences from long tree-ring records. Science 183.

— & Fritts, H. C. 1972. Tree-rings and sunspot numbers. Tree-Ring Bulletin 32.

Leikola, M. 1969. The influence of environmental factors on the diameter growth of forest trees. Acta For. Fenn. 92.

— , Raulo, J. & Pukkala, T. 1982. Männyn ja kuusen siemensadon vaihteluiden ennustaminen. Folia For. 537.

Leskinen, E. 1974. Dynaamisten stokastisten siirtofunktio-kohinamallien rakentamisesta ja malleilla ennustamisesta aikasarja-analyysissa sekä menetelmien tietokonesovelluksista. Jyväskylän Yliopiston tilastotieteen laitoksen julkaisuja 3.

— 1977. Aika-alueen keinoista mallien rakentamisessa: Auto- ja ristikorrelaatioanalyysistä. Suomen tilastoseuran julkaisuja 4: Aikasarja-analyysin menetelmiä.

Mikola, P. 1950. Puiden kasvun vaihteluista ja niiden merkityksestä kasvututkimuksessa. Commun. Inst. For. Fenn. 38.5.

Mitscherlich, G., Moll, W., Kunstle, E. & Maurer, P. 1966. Ertragskundlich-ökologische Untersuchungen in Rein- und Mischbestand VI. Zuwachsbeginn und -ende, Starkenänderung und Durchmesserzuwachs. Allg. Forst- u. Jagdzeitung 137.

Müller, H.-N. 1981. Messungen zur Beziehung Klimafaktoren – Jahrringwachstum von Nadelbaumarten verschiedener waldgrenznaher Standorte. Mitt. Forstl. VersAnst. 142/II.

Ojansuu, R. & Henttonen, H. 1983. Kuukauden keskilämpötilan, lämpösumman ja sademäärän paikallisten arvojen johtaminen Ilmatieteen laitoksen mittaustiedoista. Silva Fenn. 17(2).

Ording, A. 1941. Årringanalyser på gran og furu. Medd. Norsk. Skogsforsøksv. 7(2).

Raulo, J. & Leikola, M. 1974. Tutkimuksia puiden vuotuisen pituuskasvun ajoittumisesta. Commun. Inst. For. Fenn. 81.2.

Roiko-Jokela, P. 1976. Über Beziehungen zwischen Zuwachsindex und Klima. Beiheft zu den Zeitschriften des Schweizerischen Forstvereins 57.

Romell, L.-G. 1925. Växttidsundersökningar å tall och gran. Medd. från statens skogsförsöksanst. 22.

Sirén, G. 1961. Skogsgränstallen som indikator för klimatfluktuationerna i norra Fennoskandien under historisk tid. Commun. Inst. For. Fenn. 54.

Slåstad, T. 1957. Årringsundersökelser i Gulbrandsdalen. Medd. Norsk. Skogsförsöksv. 48.

Strand, L. 1967. Annual ring index series based on continuous sampling. XIV IUFRO-Kongress. München. Referate VI. Section 25.

Thammincha, S. 1981. Climatic variation in radial growth of Scots pine and Norway spruce and its importance in growth estimation. Acta For. Fenn. 171.

Tiihonen, P. 1979. Puiden kasvun vaihtelu valtakunnan metsien 6. inventoinnin aineiston perusteella. Folia For. 407.

Tiren, L. 1935. Om granens kottsättning, dess periodicitet och samband med temperatur och nederbörd. Medd. från statens skogsförsöksanst. 28.

Wallen, A. 1917. Om temperaturens och nederbördens inverkan på granens och tallens radietillväxt å Stamnäs kronopark 1891—1904. Skogshögskolans festskrift 1917.

Öller, L.-E. 1977. Katsaus jakautuneiden viiveiden malleihin ja niiden estimointiin liittyviin ongelmiin. Suomen Tilastoseuran julkaisuja 4: Aikasarja-analyysin menetelmiä.

Total of 55 references

SELOSTE

VUOSILUSTOINDEKSIEN RIIPPUVUUS ILMASTOTEKIJÖISTÄ

Työssä käsiteltiin 7 kuusen ja 12 männyn paikallista, eri tutkijoiden esittämää, vuosilustoindeksisarjaa, joista yksi männyn sarja oli Pallasjärveltä ja loput Etelä-Suomesta (Kuva 1). Kaikista kasvuindeksisarjoista tutkittiin niiden autoregressiivisiä ominaisuuksia. Kuuden kuusen ja seitsemän männyn indeksisarjan perusteella tarkastettiin ilmastotekijoiden vaikutusta indeksien vaihteluun korrelaatioanalyysillä, jakautuneiden viiveiden malleilla sekä siirtofunktio-kohinamalleilla. Indeksisarjojen vaihtelua selittävinä ilmastotekijöinä kokeiltiin kuukausien sademääriä, keskilämpötiloja ja niiden perusteella laskettuja lämpösummia. Keskilämpötilat ja sademäärät laskettiin tasoittamalla indeksisarjojen sijaintipaikkakuntien ympäristön säähavaintoasemien mittaustietoja.

Kaikissa tarkastelluissa männyn indeksisarjoissa ja kuudessa kuusen indeksisarjassa autokorrelaatiot viiveellä 1 olivat merkitseviä (kuvat 2, 5 ja 7). Erot indeksisarjojen autokorrelaatiofunktioiden rakenteissa olivat kuitenkin huomattavia varsinkin männyn sarjoissa, joista löytyi oletettuja AR(1)-rakenteita, kausivaihteluja ja trendejä (kuvat 5 ja 7). Jokaiselle indeksisarjalle identifioitiin ARIMA-malli, jotka on esitetty liitteessä. ARIMA-malleilla esivalkaistujen indeksisarjojen väliset korrelaatiot olivat suurempia ja riippuvuus havaintopisteiden välisestä etäisyydestä oli selvempi kuin alkuperäisillä indeksisarjoilla (kuvat 4 ja 8).

Kokeilluista ilmastotekijöistä kuusen kasvun vaihtelua selitti parhaiten kasvukauden lämpösumma. Edellisen kasvukauden loppuosan lämpimyyden vaikutus oli ristikorrelaatio- ja regressioanalyysin perusteella kasvua vähentävä. Jakautuneiden viiveiden mallien parametrien estimaatit on esitetty taulukoissa 5–7 ja lämpösummien ja indeksien logaritmien välisiä ristikorrelaatioita taulukossa 3 ja kuvissa 10–12. Identifioidut siirtofunktiokohinamallit ja estimoidut parametrit on esitetty sivulla 26.

Korrelaatioanalyysin ja jakautuneiden viiveiden mallien perusteella sademäärä vaikutti lämpötilatunnuksia tärkeämmältä tekijältä männyn kasvun vaihtelulle. Ilmastotunnusten ja indeksien logaritmien välisten ristikorrelaatioiden estimaatteja on esitetty taulukossa 4. Jakautuneiden viiveiden mallien parametrien estimaatit ovat taulukoissa 8–10. Siirtofunktio- kohinamalleissa (sivu 28) kasvukauden loppuosan lämpimyyden merkitys kuitenkin kasvoi. Sademäärän vaikutus oli siirtofunktiokohinamalleissakin merkitsevä kaikissa Etelä-Suomen indeksisarjoissa ja erittäin merkitsevä niissä osissa aineistoa, joissa kasvupaikat olivat keskimäärin karuimpia.

APPENDIX 1.

The fitted ARIMA models for the Norway spruce index series:

RUOTSINKYLÄ (AR(1))

$$Y_t = \frac{1}{(1-.594B)}\,\hat{a}_t \qquad s_a = 13.26$$

SIMPELE (AR(1))

$$Y_t = \frac{1}{(1-.439B)}\,\hat{a}_t \qquad s_a = 11.97$$

KOLI (AR(1))

$$Y_t = \frac{1}{(1-.554B)}\,\hat{a}_t \qquad s_a = 11.57$$

PARKANO (AR(1))

$$Y_t = \frac{1}{(1-.555B)}\,\hat{a}_t \qquad s_a = 11.91$$

HYYTIÄLÄ (AR(1))

$$Y_t = \frac{1}{(1-.635B)}\,\hat{a}_t \qquad s_a = 12.24$$

KUOREVESI (AR(2))

$$Y_t = \frac{1}{(1-.438B-.301B^2)}\,\hat{a}_t \qquad s_a = 12.81$$

The estimated autocorrelations for the residuals $\{\hat{a}_t\}$ are presented in Appendix figure 1.

The fitted ARIMA models for the Scots pine index series:

RUOTSINKYLÄ (ARIMA(0,1,1)×(0,1,1)$_{21}$)

$$\nabla\nabla_{21}Y_t = (1-.527B)(1-.747B^{21})a_t \qquad s_a = 11.38$$

KOLI 1 (AR(1))

$$Y_t = \frac{1}{(1-.550B)}\,\hat{a}_t \qquad s_a = 12.94$$

KOLI 2 (AR(1))

$$Y_t = \frac{1}{(1-.593B)}\,\hat{a}_t \qquad s_a = 15.42$$

KARVIA (ARIMA(0,1,1)×(0,1,1)$_{22}$)

$$\nabla\nabla_{22}Y_t = (1-.501B)(1-.721B^{22})a_t \qquad s_a = 14.22$$

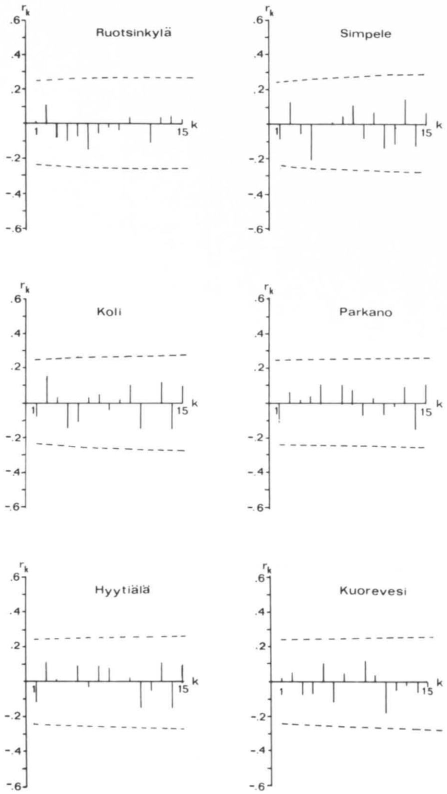
PUNKAHARJU (AR(1))

$$Y_t = \frac{1}{(1-.632B)}\,\hat{a}_t \qquad s_a = 14.03$$

HYYTIÄLÄ (AR(1))

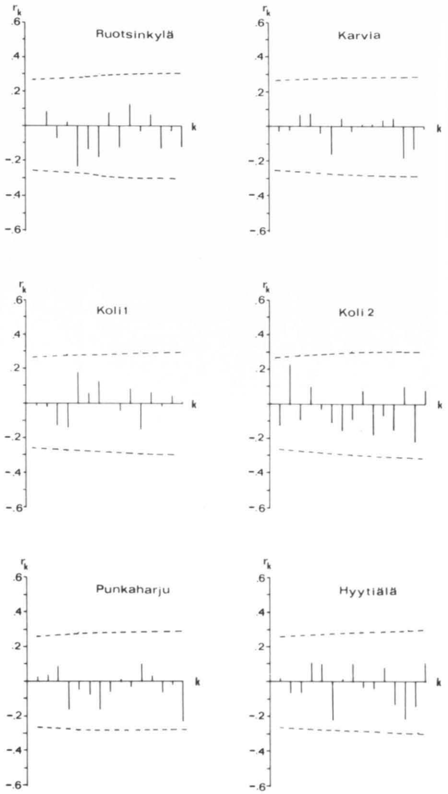
$$Y_t = \frac{1}{(1-.352B)}\,\hat{a}_t \qquad s_a = 14.05$$

The estimated autocorrelations for the residuals $\{\hat{a}_t\}$ are presented in Appendix figure 2.



Appendix figure 1. The estimated autocorrelations versus the lag k (k=1, . . . ,15) for the residuals $\{\hat{a}_t\}$ of ARIMA models fitted for the Norway spruce indices of Thammincha (1981). (-----) = 2S.E.(r_k).

Liitekuva 1. Thamminchan (1981) kuusen indeksisarjoille laadittujen ARIMA-mallien jäännösten $\{\hat{a}_t\}$ autokorrelaatioiden estimaatteja viiveen k arvoilla 1–15. (-----) = 2S.E.(r_k).



Appendix figure 2. The estimated autocorrelations versus the lag k (k=1, . . . ,15) for the residuals $\{\hat{a}_t\}$ of ARIMA models fitted for the Scots pine indices of Thammincha (1981). (-----) = 2S.E.(r_k).

Liitekuva 2. Thamminchan (1981) männyn vuosilustoindeksisarjoille laadittujen ARIMA-mallien jäännösten $\{\hat{a}_t\}$ autokorrelaatioiden estimaatteja viiveen k arvoilla 1–15. (-----) = 2S.E.(r_k).

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HENTTONEN, H. 1984. The dependence of annual ring indices on some climatic factors. Seloste: Vuosilustoindeksien riippuvuus ilmastotekijöistä. Acta For. Fenn. 186: 1–38.

Annual ring index series of Norway spruce and Scots pine from different authors were studied. ARIMA models were fitted for each series. The differences in the structures of indices from different Finnish localities and authors were noticeable.

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168 Wuolijoki, E. 1981. Effects of simulated tractor vibration on the psychophysiological and mechanical functions of the driver: Comparison of some exitatory frequencies. Seloste: Traktorin simuloidun tärinän vaikutukset kuljettajan psykofysiologisiin ja mekaanisiin toimintoihin: Eräiden herätetaajuuksien vertailu.

169 Chung, M.-S. 1981. Flowering characteristics of *Pinus sylvestris* L. with special emphasis on the reproductive adaptation to local temperature factor. Seloste: Männyn (*Pinus sylvestris* L.) kukkimisominaisuuksista, erityisesti kukkimisen sopeutumisesta paikalliseen lämpöilmastoon.

170 Savolainen, R. & Kellomäki, S. 1981. Metsän maisemallinen arvostus. Summary: Scenic value of forest landscape.

171 Thammincha, S. 1981. Climatic variation in radial growth of Scots pine and Norway spruce and its importance to growth estimation. Seloste: Männyn ja kuusen sädekasvun ilmastollinen vaihtelu ja sen merkitys kasvun arvioinnissa.

172 Westman, C. J. 1981. Fertility of surface peat in relation to the site type class and potential stand growth. Seloste: Pintaturpeen viljavuuden tunnukset suhteessa kasvupaikkatyyppiin ja puuston kasvupotentiaaliin.

173 Chung, M.-S. 1981. Biochemical methods for determining population structure in *Pinus sylvestris* L. Seloste: Männyn (*Pinus sylvestris* L.) populaatiorakenteesta biokemiallisten tutkimusten valossa.

174 Kilkki, P. & Varmola, M. 1981. Taper curve models for Scots pine and their applications. Seloste: Männyn runkokäyrämalleja ja niiden sovellutuksia.

175 Leikola, M. 1981. Suomen metsätieteellisen julkaisutoiminnan rakenne ja määrällinen kehitys vv. 1909–1978. Summary: Structure and development of publishing activity in Finnish forest sciences in 1909–1978.

176 Saarilahti, M. 1982. Tutkimuksia radioaaltomenetelmien soveltuvuudesta turvemaiden kulkukelpoisuuden arvioimiseen. Summary: Studies on the possibilities of using radar techniques in detecting the trafficability of peatlands.

177 Hari, P., Kellomäki, S., Mäkelä, A., Ilonen, P., Kanninen, M., Korpilahti, E. & Nygrén, M. 1982. Metsikön varhaiskehityksen dynamiikkaa. Summary: Dynamics of early development of tree stand.

178 Turakka, A., Luukkanen, O. & Bhumibhamon, S. 1982. Notes on *Pinus kesiya* and *P. merkusii* and their natural regeneration in watershed areas of northern Thailand. Seloste: Havaintoja männyistä (*Pinus kesiya* ja *P. merkusii*) ja mäntyjen luontaisesta uudistumisesta Pohjois-Thaimaan vedenjakaja-alueilla.

179 Nyyssönen, A. & Ojansuu, R. 1982. Metsikön puutavaralajirakenteen, arvon ja arvokasvun arviointi. Summary: Assessment of timber assortments, value and value increment of tree stands.

180 Simula, M. 1983. Productivity differentials in the Finnish forest industry. Seloste: Tuottavuuden vaihtelu Suomen metsäteollisuudessa.

181 Pohtila, E. & Pohjola, T. 1983. Lehvästöruiskutuksen ajoitus kasvukauden aikana. Summary: The timing of foliage spraying during the growing season.

182 Kilkki, P. 1983. Sample trees in timber volume estimation. Seloste: Koepuut puuston tilavuuden estimoinnissa.

183 Mikkonen, E. 1983. Eräiden matemaattisen ohjelmoinnin menetelmien käyttö puunkorjuun ja kuljetuksen sekä tehdaskäsittelyn menetelmävalinnan apuvälineenä. Abstract: The usefulness of some techniques of the mathematical programming as a tool for the choice of timber harvesting system.

184 Westman, C. J. 1983. Taimitarhamaiden fysikaalisia ja kemiallisia ominaisuuksia sekä niiden suhde orgaanisen aineen määrään. Summary: Physical and physico-chemical properties of forest tree nursery soils and their relation to the amount of organic matter.

185 Kauppi, P. 1984. Stress, strain, and injury: Scots pine transplants from lifting to acclimation on the planting site. Tiivistelmä: Metsänviljelytaimien vaurioituminen noston ja istutuksen välillä.

186 Henttonen, H. 1984. The dependence of annual ring indices on some climatic factors. Seloste: Vuosilustoindeksien riippuvuus ilmastotekijöistä.

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