University of Latvia

Faculty of Biology

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PARAMETRIC ANALYSIS OF RADIAL INCREMENT OF SCOTS PINE FOR ENVIRONMENTAL ASSESSMENT

Summary of Doctoral Thesis

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Form of the thesis: dissertation in Biology, subfield ecology

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Annotation

Tjarve D., 2013. Parametric analysis of radial increment of Scots pine for environmental assessment.

The suitability of Scots pine (*Pinus sylvestris* L.) for the dendroecological assessment of environmental quality was analysed. A new method for the detection of missing and false tree-rings was developed. Five of the most frequently used growth models were fitted to the individual tree-ring series. It was concluded that thirty years and older tree rings are the best use for environmental quality assessment. Several methods of data transformation and smoothing were tested. Method was tested in 64 sample plots selected across a territory of Latvia, including 24 sample plots in surrounding of Skrunda town. In the most plots in Skrunda, a significant and permanent decrease of the growth increment was found. It indicates the presence of strong negative environmental factor. Possibly it is the impact of Skrunda radiolocation station.

Keywords: tree-rings, crossdating, growth models, Pinus sylvestris, dendroecology, methods.

Contents

Introduction

Tree growth can be affected by various factors – climate, tree age, local or global environmental changes, etc. Analysis of tree rings for retrospective assessment of environmental changes has been objective of many actual studies using various methods such as comparison of tree growth between stands with various levels of analysed factor, assessment of wood structure changes, analysis of pointer years, multiple time regression analysis, comparison of tree growth trends of different time periods, etc. (Innes 1990). Each method can be used with various modifications. Choice of method depends on analysed factor, tree species, study objectives, etc. Therefore, the specification of restrictions and possible modifications of methods depending of different circumstances is important.

Comparison of tree growth trends of different time periods can be used for the environmental factor assessment. Such analysis prevents the influence of site-specific factors, and parametric analysis can be used. One of the most important problems is the elimination of age-related factors. These factors can be specific for various tree species and regions.

Scots pine (*Pinus sylvestris* L.) is a most common tree species in Latvia. Here it is located in the middle of its natural range (Kelly, Conolly 2000), and the influence of climatic factors on pine growth here is relatively low (Elferts 2008). Therefore, Scots pine is one of the most suitable tree species for environmental factor assessment in Latvia.

Scots pine is commonly used for environmental assessment in Europe and Latvia, and various methods have been used (Liepa 1996; Juknys et al. 2003; Erlyckite, Vitas 2008; Mandre et al. 2008; Szymura et al. 2010). Tree growth in different time periods has been compared (Balodis et al. 1996; Pärn, Mandre 2011). However the influence of tree age-related factors is not sufficiently studied. Also the restrictions of parametric analysis are not evaluated.

Aim of the study

To justify the use of Scots pine for environmental factor parametric assessment with comparison of growth trends of different time periods, and to define restrictions of this method.

Study objectives

1. To evaluate the possibilities of cross-dating of previously undated tree-ring series.
2. To assess the suitability of the most frequently used tree-ring series models for dendroecological studies, and their relevance with age trend.
3. To define the restrictions of tree growth changes parametric assessment by finding minimum detectable difference required sample size, and estimation of test power.
4. To evaluate the necessity of data transformation and to select the best type of transformation.
5. To evaluate the suitability of high frequency filters for dendroecological studies.
6. To test the parametric method of environmental assessment by use of different modifications in sample sites across a territory of Latvia.

Hypothesis

1. Influence of age-related factors is not significant for growth trend of middle-aged Scots pine trees.
2. Logarithmic data transformation can be applied before the parametric assessment of Scots pine tree-ring width changes.
3. Persistent significant growth changes of trees in several sample sites indicate the presence of strong environmental factor.

Thesis

1. A new method for the detection of missing and false tree-rings is suitable for location of misdating tree-rings.
2. In case of age-related factor dominance, a significant growth changes cannot be detected for Scots pine trees in age period from 30 to 90 years.
3. For the parametric assessment of Scots pine growth, tree-ring data can be logarithmically transformed. In some cases, the addition of small constant is recommended.
4. In many sample plots, the persistent relative cumulative additional annual increment indicates the presence of strong environmental factor.

Scientific publications

Balodis V., Brūmelis G., Kalviškis K., Nikodemus O., Tjarve D., Znotiņa V., 1996. Does the Skrunda Radiolocation Station diminish the radial growth of pine trees? The Science of the Total Environment 180(1):57–64.

Balodis V., Pospelova G., Ramans K., Tjarve D., 1997. Dendrochronological analysis for the assessment of the environmental quality. Proceedings of the Latvian Academy of Sciences 51(5/6):219–221.

Brūmelis G., Elferts D., Liepiņa L., Lūce I., Tabors G., Tjarve D., 2005. Age and spatial structure of natural Pinus sylvestris stands in Latvia. Scandinavian Journal of Forest Research, 20:471–480.

Conferences

Balode Z., Brūmelis G., Kalviškis K., Tjarve D., Znotiņa V., 1994. Some results and problems of the evaluation of radiofrequency radiation on organisms. In: Brūmelis G. (ed.). The Effect of Radiofrequency Electromagnetic Radiation on Organisms. Proc. of the International Conference of Radio Frequency Electromagnetic Radiation on organisms, Skrunda, Latvia June 17–21, 1994.

Tjarve D., Kalniņš A., 1997. Dendroecological assessment of environmental quality of Latvia. In: Proc. of Eurodendro 97: Conference of the European Working Group for Dendrochronology, Savonlinna, Finland May 28 – June 1, 1997.

Brūmelis G., Piterāns A., Pospelova G., Ramans K., Tjarve D., Znotiņa V., 1998. Dendroecological assessment of forest health in Latvia. In: Sander H., Randrup T.B. (eds.). Urban Forestry in the Nordic and Baltic Countries. Proc. of a Nordic Workshop on Urban Forestry, Tallinn, Estonia December 1–3, 1997.

Structure of the Doctoral Thesis

The promotion work has 68 pages. Summary, introduction, conclusions, and separate chapters on literature analysis, study methods, results and discussion, as well as literature list and acknowledgements are included. Eleven figures and eleven tables are shown. Sixty-five annexes on 49 pages are added.

1. Summary

1.1. Methods

Data were analysed using R statistical software, program libraries "*stats*" (R Development Core Team 2010), "*dplR*" (Bunn 2010), and functions written by author.

1.1.1. Sample collection

Tree-ring samples were sampled with increment borer at breast height (1.3 m), from the side selected by chance during summer and autumn seasons from 1989 to 2010, in all territory of Latvia.

Totally, 3072 tree-ring series of Scots pine trunks in 159 sampling sites were collected. Only trees with at least 30 tree-rings were sampled. Additionally, 175 tree-ring series of Norway spruce from 10 sample sites were sampled, for the development of method for detection of missing and false tree-rings.

For 65 sampling sites with at least 10 tree-ring series where first year was 1935 or earlier, mean relative additional and relative cumulative additional annual increment was calculated.

All Norway spruce tree ring series and 254 Scots pine tree-ring series from 12 sampling sites were cross-dated by COFECA software (Grissino-Mayer 2001). For the rest tree-ring series, cross-dating was not applied.

1.1.2. Method for missing and false tree-ring detection

For the development of the method, all cross-dated tree-ring series of Scots pine and Norway spruce were used.

Standardization of tree-ring series by removal of autoregression was used. Master chronology for each sampling site was calculated as a mean of all master chronology series using Tukey's biweight robust mean, function *tbrm* from R statistical software program library "*dplR*".

If a possible occurrence of missing tree-ring was found, by splitting the existing tree-ring a new tree-ring series were created for each of the potentially problematic years. Using proportions of appropriate years in master chronology, tree-rings were split. In a case of false tree-ring detection, new series were created with merging two tree-rings. Each of new tree-ring series was divided in segments of the same length. First segment starts with the last year of growth. Next segments are lagged by appropriate lag period. Each segment correlation with master chronology was computed, and mean of Pearson correlation coefficient for each of tree-ring series was calculated. Tree-ring series with the best correlation were found, and it was assumed that the year with previously changed tree-ring potentially was the year with false or missing tree-ring.

To test this method, the occurrence of false and missing tree-rings was simulated. By splitting existing rings in random proportions, new series of false rings were created, and by merging two rings new series of missing rings were created. Totally, 19 186 pine, and 12 304 spruce series with false rings and 19 069 pine, and 12 253 spruce series with missing rings were created.

Each of the created tree-ring series was tested with method for detection of missing and false tree-rings, and finding success was calculated. Tree variants of segment length (40, 50, 60 years) as well as tree variants of lag period (5, 10, 20 years) were tested.

1.1.3. Models of tree-ring series

Five of the most frequently used models by dendrochronological studies (linear, negative exponential, power, hyperbolic, and generalised exponential) were fitted to the individual tree-ring series.

Function *lm* from R statistical software program library "*stats*" for fitting, and statistical test of linear models were used. Function *nls* was used for other models. Only models with significant ($p \leq 0.05$) coefficients were used. Selection of the best models was based on Akaike's information criterion (AIC). All models with $AIC_i - AIC_{min} < 2$, where AIC_i – AIC of tested model, and AIC_{min} – minimal AIC value were selected (Burnham, Anderson 2002).

1.1.4. Differences of predicted values of models

For all fitted models based on full tree-ring series, predicted tree-ring width series with 90 logarithmically transformed and untransformed values were calculated.

For each of the predicted series, absolute values of difference between predicted values of 1^{st} and 60^{th}, 11^{th} and 70^{th}, 21^{st} and 80^{th}, 31^{st} and 90^{th} tree-ring widths were calculated. Absolute values of differences were grouped by model type. Percentiles at 5%, 25%, 50%, 75%, and 95% for each group were calculated.

1.1.5. Data transformation

Logarithmic transformation and smoothing were used before the calculation of relative additional annual increment.

Three methods of logarithmic transformation were used – 1) simple use of natural logarithm; 2) adding of constant $c = 0.5$ before transformation; 3) adding of specific constant for each site $c = x$ where $x \leq 2$; it provides lowest linear dependence between mean and standard deviations.

Three methods of data smoothing were used – 1) polynomial smoothing

$$w`_{tr}(i,t,l) = (-3w_{tr}(i,t\text{-}2,l) + 12w_{tr}(i,t\text{-}1,l) + 17w_{tr}(i,t,l) + 12w_{tr}(i,t\text{-}1,l) - 3w_{tr}(i,t\text{-}2,l)) / 35, \quad (1.1)$$

where w'_{tr} – smoothed value of tree-ring width of series (i), year (t), and sample site (l), w_{tr} – transformed value of tree-ring width (Balodis et al. 1997); 2) cubic-smoothing spline with 50% frequency-response cutoff, and eleven or 3) twenty year filter length. Cubic-smoothing spline was applied by function *ffcsaps* from R statistical software program library "*dplR*".

1.1.6. Relative additional annual increment

Relative additional annual increment can be calculated for each tree (i) with comparison of radial increment in year (t) with radial increment in control period $\Delta t_c = t_1 \ldots t_2$, where t_1 – first year, t_2 – last year in control period, n_c – number of years of control period:

$$d(i,t,|\Delta t_c) = w'_{tr}(i,t) - \overline{w}'_c(i,\Delta t_c)\,, \quad (1.2)$$

$$\text{where } \overline{w}_c(i,\Delta t_c) = (\sum_{t=t_1}^{t_2} w'_{tr}(i,t)) / n_c\,. \quad (1.3)$$

In this study $t_1 = 1955$, $t_2 = 1965$, and $n_c = 11$ in all cases.

Mean relative additional annual increment for each sample site (l) with number of trees (n) in year (t) was

$$\overline{d}(t,l|\Delta t_c) = (\sum_{i=1}^{n} d(i,t,l|\Delta t_c)) / n\,. \quad (1.4)$$

Two-tailed null hypothesis $H_0 : \overline{d}(t, l | \Delta t_c) = 0$ concerning the difference between two population means was parametrically tested with *t* test. If mean relative additional annual increment was significantly positive than radial growth was better than in control period, if negative – it has become worse.

1.1.7. Relative cumulative additional annual increment

Accumulated radial increment within retrospective period $\Delta t_c = t_3 \ldots t_4$, where t_3 – first year of retrospective period, and t_4 – last year, can be calculated for each tree (*i*) as a relative cumulative additional annual increment

$$D_r(i, \Delta t_c, l | \Delta t_c) = (\sum_{t=t_3}^{t_4} d(i, t, l | \Delta t_c)) / n_r . \qquad (1.5)$$

where n_r – length of retrospective period. In this study n_r = 10 in all cases.

Mean relative cumulative additional annual increment for each sample site (*l*) with number of trees (*n*) was

$$\overline{D}_r(i, \Delta t_r, l | \Delta t_c) = (\sum_{i=1}^{n} D_r(i, \Delta t_c, l | \Delta t_c)) / n . \qquad (1.6)$$

1.1.8. Minimum detectable difference between tree-ring widths

To estimate minimum detectable difference (δ) between tree-ring widths, a following formula can be used:

$$\delta = \sqrt{\frac{s_p^2}{n}} (t_{\alpha(2),\nu} + t_{\beta(1),\nu}) , \qquad (1.7)$$

where *n* – sample size, s^2_p – pooled variance, $\alpha(2)$ – significance level for two-tailed *t* test, $\beta(1)$ – probability of committing II type error for one-tailed *t* test (Zar 1996).

For the estimation of power of the test, following formula can be used:

$$t_{\beta(1),\nu} = \delta \sqrt{\frac{n}{2 s_p^2}} - t_{\alpha(2),\nu} , \qquad (1.8)$$

where power of the test is 1-β(1).

Pooled variance was calculated by using 46 sample sites with at least 20 trees. Every tree was more than 60 years old. Totally, 1702 tree-ring samples were obtained. Each of them belongs to another sample site and year. Pooled variance for untransformed and logarithmically transformed data was calculated using following formula:

$$s_p^2 = \sum_{i=1}^{n} \nu_i s_i^2 \Big/ \sum_{i=1}^{n} \nu_i , \qquad (1.9)$$

where s^2_i – variance of each sample, *n* – number of samples, ν_i – number of freedom degrees.

1.2. Results and discussion

1.2.1. Detection of missing and false tree-rings

The best results of missing and false tree-ring detection for both tree species – Scots pine and Norway spruce – were found within longer segments (60 years), and for 10 or 20-year lag period. However, differences between variants are not large and do not exceed 4%.

Detection of missing tree-rings was successful for more than 70% of tests for both tree species. For false tree-rings, test success exceeded 50%. Detection success was substantially higher in all cases if a little inaccuracy was allowed. If five-year error for misdating ring detection was allowed, detection success exceeded 80% (Fig. 1.1). Such results can facilitate visual location of missing or false tree-ring.

Detection success of misdating tree-rings for Norway spruce depends from quality of chronology: significant correlation between expressed population signal (EPS) and detection success was found. For tree-ring series of Scots pine, significant correlation was not found.

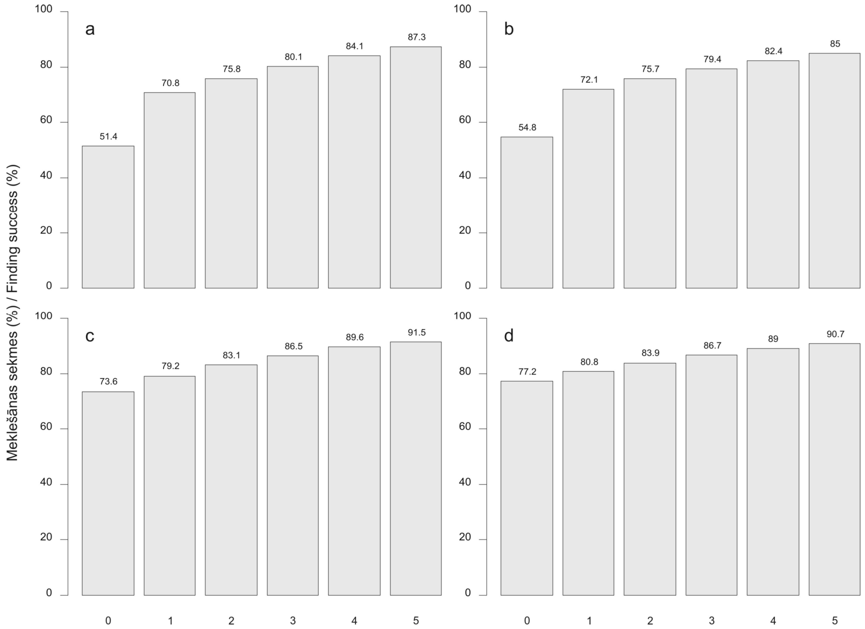

Figure 1.1. Misdating tree-ring detection success with different allowed detection error (0 to 5 years).

a – false ring detection success for Norway spruce; b – false ring detection success for Scots pine; c – missing ring detection success for Norway spruce; d – missing ring detection success for Scots pine.

1.2.2. Minimum detectable difference between tree-ring widths

Pooled variance and standard deviation of untransformed and logarithmically transformed tree-ring widths were estimated using formula (1.9). For untransformed data $s^2 = 0.256$, $s = 0.506$, for logarithmically transformed – $s^2 = 0.167$, $s = 0.409$.

Null hypothesis assumes that mean values of tree-ring widths of two years are equal. Minimum detectable difference between tree-ring widths was calculated using formula (1.7), with previously estimated pooled variance and probability of II type error $\beta = 0.1$ using various sample sizes and significance levels (Table 1.1).

Table 1.1

Minimum detectable difference (δ) between untransformed and logarithmically transformed two year tree-ring widths using *t* test with standard deviations $s = 0.506$ and $s = 0.409$, probability of committing Type II error $\beta = 0.1$, various significance levels ($\alpha = 0.1$, 0.05, 0.01, 0.001), and sample sizes (*n*).

	δ (mm)		log(δ)	
n	α = 0.01	α = 0.05	α = 0.01	α = 0.05
10	1.05	0.82	0.85	0.67
15	0.80	0.64	0.65	0.52
20	0.67	0.55	0.54	0.44
25	0.59	0.48	0.48	0.39
30	0.53	0.44	0.43	0.35

1.2.3. Models of tree-ring series

Five models were fitted to the Scots pine tree-ring series that contained at least 50 tree-rings. At least one model was significant for 94.3% of series. For most of tree-ring series more than one significant model could be applied. Linear, power, and hyperbolic models were significant ($p \leq 0.05$) more often. Less frequently negative exponential and generalised exponential models were significant (Fig. 1.2).

However, generalised exponential model was the most frequent (for 33.6% of tree-ring series) best-fitted model with minimum AIC value. For linear, negative exponential, power, and hyperbolic models, minimum AIC value was best-fitted only for 14% to 17% tree-ring series. If selection of the best-fitted models was based on assumption $AIC_i - AIC_{min} < 2$, generalised exponential model had the best-fit for 35% of tree-ring series; but other models had the best-fit for 17% to 25% of series (Fig. 1.2).

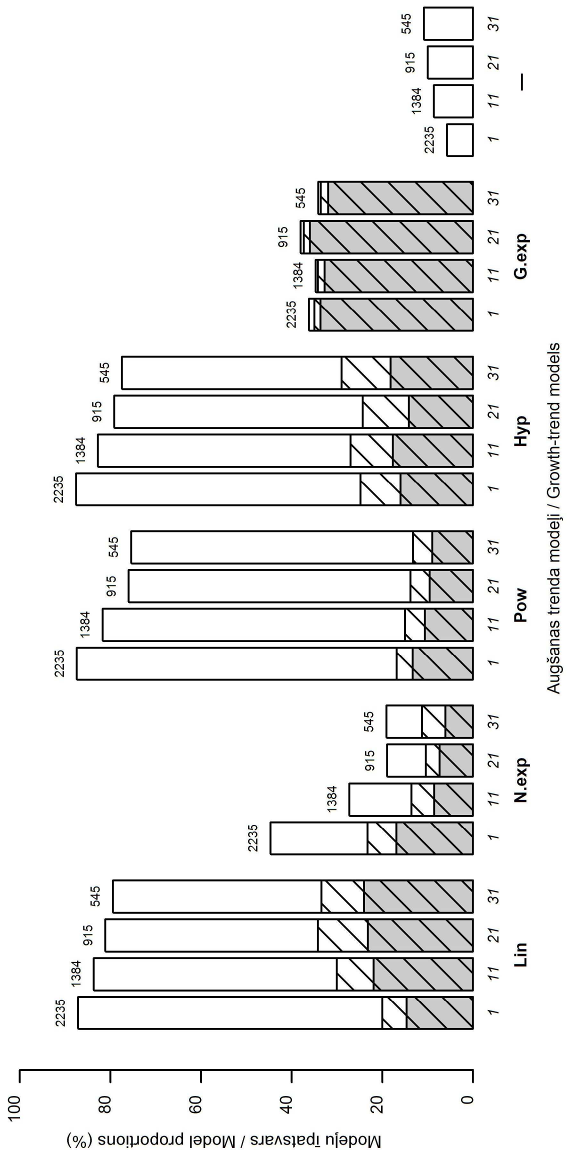

Figure 1.2. Proportion (%) of five growth trend models of Scots pine tree ring series.

Series begin at 1st, 11th, 21st, and 31st tree-ring of the sample with at least 50 tree-rings. White, shaded and striped bars indicate proportion of significant ($p \leq 0.05$), one best ($AIC = AIC_{min}$), and best ($AIC - AIC_{min} < 2$) model proportion accordingly. Models: **Lin** – linear, **N.exp** – negative exponential, **Pow** – power, **Hyp** – hyperbolic, **G.exp** – generalised exponential, — – no significant models. Above bars – numbers of tested series.

Proportion of significant and best-fit models slightly changed if model fitting was based on tree-ring series without the first years. Proportion of significant models decreased for all model types except generalised exponential models. Largest decrease was found if first ten years were excluded from tree-ring series. Decrease was lesser if 20 or 30 years were excluded (Fig. 1.2).

1.2.4. Model characterisation

Models of tree-ring series often are used for dendrochronological studies, for removal of age-related trend. However, the separation of age-related trend from environmental signal is problematic. Therefore, more often these models can be used to remove growth trend. Growth trend includes both age-related trend and environmental signal (Cook 1990).

Exponential decrease of growth, which is typical for age-related growth trend of conifers, often can be characterized with negative exponential function (Fritts 1976). This model was significant for less than fifty percents of tree-ring series analysed in this study. However, this model was one of the best-fit models only for twenty-five percents of the series (Fig. 1.2). One of possible reasons could be the sampling of wood cores at breast height. In this way, tree-ring series do not include a few of the first tree-rings, but for later years of growth decrease is not so strong. Another reason could be related with environmental factors if these are stronger than age-related factors. For this case, other models are better.

Power function fit the age-related growth increment somewhat better than negative exponential function (Kuusela, Kilkki 1963). Power model was one of the best-fitted models only for less than twenty percent of series. However, this model was significant for ~90% of series (Fig. 1.2).

Power model can be used for characterization of age-related trend, and it is better-fitted than negative exponential model for trees of forest stands where mortality rate of trees is not linear over time (Cook 1985). Age structure of some 200 years old Scots pine forests in Latvia is not even, and regeneration is intensive within short periods. Possibly, age structure is formed as a result of changing mortality rate (Brūmelis et al. 2005). Therefore, for many of trees in unmanaged forests, the power model can be expected.

Generalised exponential function is theoretically more complicated than negative exponential model, and can fit to unimodal growth trend. Therefore, this function can be used for modelling disturbance pulses

(Warren 1980), and it can characterize the juvenile increase of radial growth and later exponential decrease, which is typical for closed stands (Cook et al. 1990). This model was one of the best-fitted models for one third of the tree-ring series (Fig. 1.2). However, generalised exponential model was not significant for most of the tree-ring series. Possibly, it cannot fit to a series without suppression-release events in tree-rings.

If growth trend does not have exponential decrease phase at growth start, linear and hyperbolic functions are best-fitted to tree-ring series. Both models are best-fitted for slightly more than one third of analysed series (Fig. 1.2). In most cases, these models have larger decrease within the late growth period than negative exponential and power models (Table 1.2). Possibly, such decrease is related to long-term negative environmental factors.

Negative exponential and power models possibly are appropriate for fitting of an age-related growth trend. If different environmental factors are dominated, other models are best-fitted.

Most of the best-fitted models in this study could be linearized by logarithmical transformation. Possibly, tree-ring widths are distributed rather lognormally then normally. Therefore, tree-ring width data can be logarithmically transformed before the use of parametric methods.

1.2.5. Differences between tree-ring widths

Differences between tree-ring widths predicted with previously fitted models were calculated. Tree-rings with 60 years interval for each model were used. Absolute values of differences were grouped by model type, and percentiles for each group were calculated (Table 1.2).

Largest differences were between 1st and 60th, smallest – between 31st and 90th tree-rings for all model groups. However, percentiles of differences considerably differed between the model groups. Largest absolute values of differences between 1st and 60th predicted tree-ring widths were found for negative exponential and power models. However largest values between 21st – 80th and 31st – 90th tree-ring widths were for hyperbolic and generalised exponential models (Table 1.2).

By using parametric test, these values were compared with minimum detectable differences (Table 1.1). For more than half of all model groups, differences between 1st – 60th and 11th – 70th predicted values were larger

than minimum detectable differences at significance level $\alpha = 0.05$ and sample size $n = 20$.

Table 1.2

Percentiles of absolute values of differences between two predicted untransformed and logarithmically transformed tree-ring widths (w) of different years $\delta = |w_{t1} - w_{t2}|$ for four model types.

Only best models (AIC - AIC_{min} < 2) were used.

		δ (mm)			log (δ)		
t_1	t_2	25%	50%	75%	25%	50%	75%
Negative exponential models (n = 519)							
1.	60.	1.71	2.73	4.28	0.93	1.27	1.64
11.	70.	0.44	0.84	1.32	0.31	0.57	0.89
21.	80.	0.07	0.29	0.62	0.06	0.23	0.54
31.	90.	0.01	0.10	0.32	0.01	0.08	0.30
Power models (n = 376)							
1.	60.	1.14	2.11	3.67	0.71	1.12	1.56
11.	70.	0.42	0.67	1.01	0.32	0.51	0.71
21.	80.	0.28	0.44	0.63	0.23	0.37	0.51
31.	90.	0.21	0.32	0.46	0.19	0.29	0.41
Hyperbolic models (n = 554)							
1.	60.	1.01	1.74	3.04	0.66	1.09	1.60
11.	70.	0.78	1.16	1.61	0.60	0.92	1.22
21.	80.	0.60	0.84	1.11	0.56	0.80	1.00
31.	90.	0.46	0.62	0.83	0.52	0.70	0.85
Generalised exponential models (n = 782)							
1.	60.	0.73	1.49	2.82	0.73	1.49	2.82
11.	70.	0.51	0.98	1.66	0.51	0.98	1.66
21.	80.	0.42	0.83	1.35	0.42	0.83	1.35
31.	90.	0.37	0.75	1.28	0.37	0.75	1.28

For more than half of the negative exponential and power models differences between 21st and 80th predicted values were smaller than minimum detectable differences. Differences between 31st and 90th values were smaller for more than one fourth of both model groups.

Age-related exponential decrease is larger at the start of tree growth (Fritts 1976; Cook 1990), and it can explain large differences between 1st – 60th and 11th – 70th predicted values. However, for hyperbolic and generalised exponential models, difference is large also later. Possibly, it depends from other factors.

In most cases, differences between 21st – 80th and 31th – 90th predicted values for negative exponential and power models were smaller than minimum detectable differences. These models were associated with age-related factors rather than other. In most cases, differences could not be parametrically assessed between tree-ring widths, if main factor was tree age after 20th tree-ring, from wood cores obtained at breast height. If differences were significant for many years in succession, we can assume that tree growth was affected by non-age-related factors. Therefore, sufficiently old Scots pine trees can be used for environmental factor assessment.

1.2.6. Data transformation and smoothing

Data can be logarithmically transformed, if tree-ring widths are lognormally distributed. Logarithmic transformation reduced the relationship between mean and standard deviation of tree-ring width data. However, in case of presence of small values, negative skew of probability distribution can be formed (Cook et al. 1990). One of possible ways of variance stabilization is the adding of a small constant before the logarithmic transformation (Cook, Peters 1997).

Mean and standard deviation was calculated using various smoothing methods and untransformed or logarithmically transformed data. Calculation was applied for each tree-ring series of 65 sampling sites, and mean relative cumulative additional annual increment using tree-ring widths of years from 1955 to 1984 was estimated. To characterize mean-to-standard deviation relationship, Pearson correlation coefficient for each of sampling site was calculated.

For untransformed data with or without smoothing, relationship was relatively high – $\bar{r} = 0.45 \ldots 0.62$. In case of logarithmically transformed data, negative relationship was observed – $\bar{r} = -0.41 \ldots -0.38$. However, absolute values of correlation coefficient were lower. By adding constant

$\bar{r} = -0.41 \ldots -0.38$ before logarithmical transformation, the lowest relationship was observed. Therefore, logarithmical transformation before parametric analysis, possibly with adding a small constant can be recommended. In this way, the specific constant with lowest mean-to-standard deviation relationship for each sample site can be obtained. If limits of constant from null to two were assumed, mean value of those was 0.8 and median – 0.5.

1.2.7. Relative additional annual increment

Relative additional annual increment was calculated using control period from 1955 to 1965 for each of 65 sample sites with at least 10 trees. Three methods of data transformation as well as four methods of data smoothing were used. Totally, 12 variants were tested.

Depending of data transformation method, mean number of years per sample site with significant mean relative additional annual increment was from 10.4 to 11.4 (Table 1.3).

If data smoothing was not used, mean number of years was the highest. In this case, however, mean number of years per sample site with significant mean relative additional annual increment and low power of the test ($1-\beta < 0.9$) was also highest. It was lowest if cubic-smoothing spline was used. Moreover, the mean number of years with height power of the test ($1-\beta \geq 0.9$) was highest (Table 1.3d, e). Power of the test between two variants – using appropriate data smoothing method or not using for each year with significant mean relative additional annual increment in both cases was compared. By using cubic-smoothing spline, the highest mean number of years was observed (Table 1.3h, i).

If variants with adding the constant before logarithmic transformation and not adding were compared, the highest mean number of years with highest power of the test was observed in case if polynomial smoothing was used or smoothing was not applied (Table 1.3f, g).

If constant $c = 0.5$ rather then estimated constant was added, better results in terms of power of the test was obtained (Table 1.3f, g). Possibly, each sample site included groups of tree-ring series with various mean-to-standard deviation relationships (Cook et al. 1990), and it diminished the effect of constant adding.

So, adding of constant before logarithmic transformation for the calculation of mean relative additional annual increment can be preferred if data smoothing is not applied or polynomial smoothing is used. Possibly, site-specific data transformation methods can be used. However, selection of the method must be supported in this case for both mean-to-standard deviation relationship and analysis of test power.

Table 1.3

Mean number of years per plot with significant ($p \leq 0.05$) relative additional annual increment.

a – data smoothing type (Log – logarithmically transformed without smoothing, Poly – logarithmically transformed with polynomial smoothing, Spline (11), Spline (20) – logarithmically transformed cubic-smoothing spline with filter length 11 and 20 years); b – value of constant, added before logarithmic transformation (x – estimated constant with lower mean-to-standard deviation relationships); c – years with significant relative additional annual increment; d – years with test power 1-β ≥ 0.9; e – years with test power 1-β < 0.9; f, g – years with higher (f) or lower (g) test power with constant added before logarithmic transformation; h, i – years with higher (h) or lower (i) test power using data smoothing methods.

a	b	c	d	e	f	g	h	i
Log	c = 0	11.3	4.8	6.6				
	c = 0.5	11.4	4.9	6.5	4.4	3.1		
	c = x	11.4	4.9	6.5	4.0	3.4		
Poly	c = 0	10.4	4.4	6.0			3.8	3.3
	c = 0.5	10.5	4.3	6.2	3.7	3.1	3.5	3.6
	c = x	10.5	4.3	6.2	3.3	3.4	3.6	3.7
Spline (11)	c = 0	11.0	5.1	5.9			4.3	3.4
	c = 0.5	10.9	5.1	5.8	2.8	4.3	4.0	3.6
	c = x	10.7	5.0	5.8	2.2	4.8	3.9	3.8
Spline (20)	c = 0	11.0	5.5	5.5			4.2	3.3
	c = 0.5	10.9	5.3	5.5	2.2	4.9	4.0	3.4
	c = x	10.7	5.2	5.6	1.9	5.5	3.8	3.4

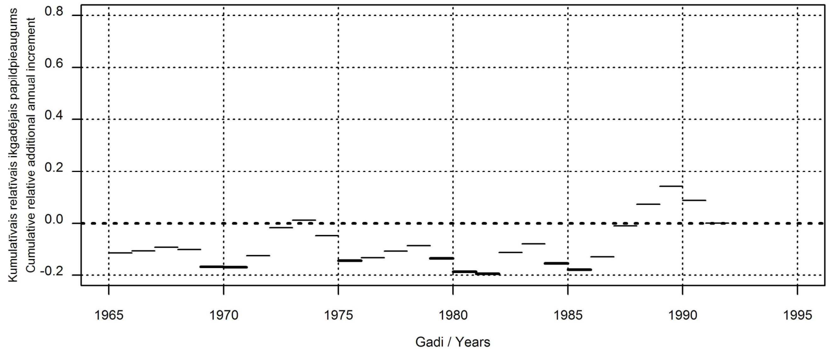

Figure 1.3. Mean relative additional annual increment in sample plot "6G07" near Babīte using logarithmically transformed data after adding a constant c = 0.5 with polynomial smoothing. Significant ($p \leq 0.05$) additional increment is shown with thick lines.

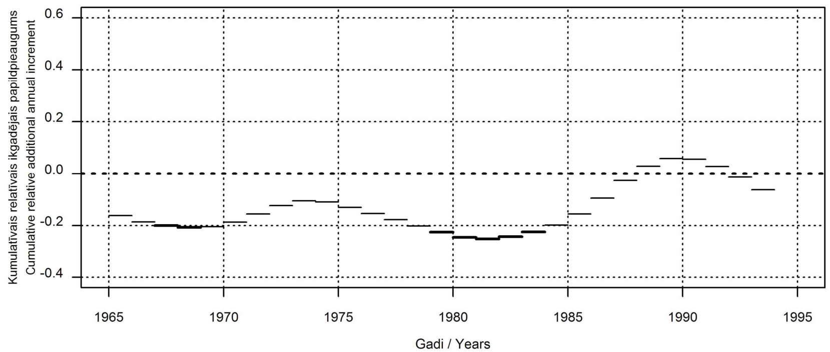

Figure 1.4. Mean relative additional annual increment in sample plot "6G07" near Babīte using cubic-smoothing spline with 11 year filter length and logarithmical transformation. Significant ($p \leq 0.05$) additional increment is shown with thick lines.

In terms of power of the test, cubic-smoothing spline is advisable compared to other smoothing methods. However, method selection possibly must be based on properties of the analysed factor. For long-term factors, smoothing methods with longer filter length can be recommended. Short-term factors can be possibly found only in cases if smoothing methods with shorter filter are used or smoothing is not applied. It can be suitable for more accurate detection of start or end year of factor influence.

With polynomial smoothing the mean relative additional annual increment for sample site "6G07" was calculated (Fig. 1.3). Time period between 1979 and 1986 with significant negative increment was found. Significant negative increment, calculated using cubic-smoothing spline with 11-year filter length, ended at 1984 (Fig. 1.4). So, time of factor influence can be detected more accurately with shorter filter length. However, power of the test was relatively low for this site, and it is possible that age-related and short-term climatic factors were determinative.

1.2.8. Relative cumulative additional annual increment

Mean cumulative relative additional annual increment was calculated using the same control period and sample sites as for calculation of relative additional annual increment. It shows accumulated increment for 10-year retrospective period.

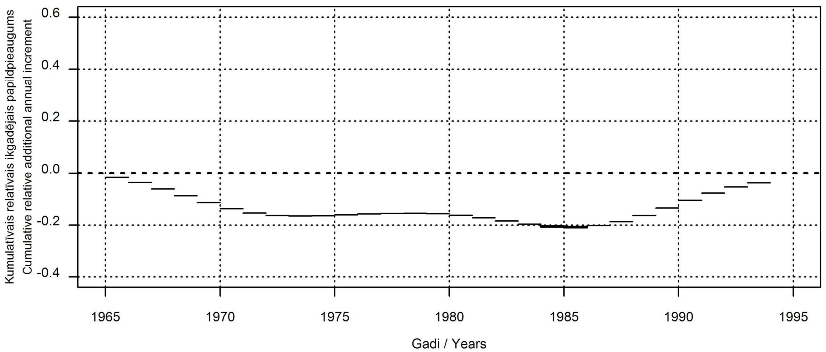

Figure 1.5. Mean relative cumulative additional annual increment in sample plot "6G07" near Babīte calculated using cubic-smoothing spline with 11-year filter length and logarithmical transformation. Significant ($p \leq 0.05$) additional increment is shown with thick lines.

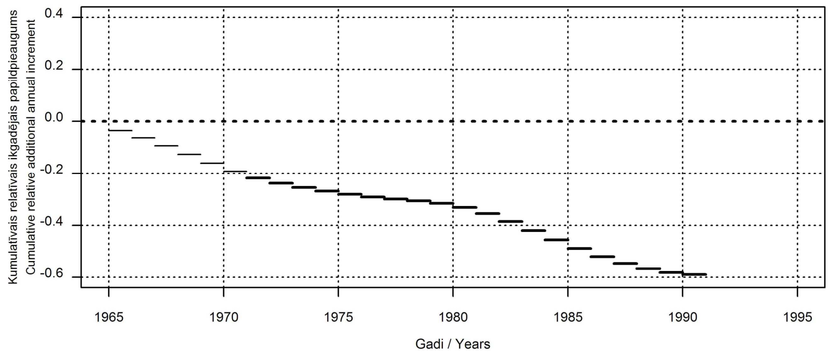

Figure 1.6. Mean relative cumulative additional annual increment in sample plot "6G07" near Babīte calculated using cubic-smoothing spline with 11-year filter length and logarithmical transformation. Significant ($p \leq 0.05$) additional increment is shown with thick lines.

Mean number of years per sample site with significant mean relative cumulative additional annual increment was from 7.6 to 9.1. Power of test was lower when using constant adding before logarithmic transformation compared with using simple logarithmic transformation, therefore the later is more applicable. Ten-year retrospective period is comparatively long; therefore the selection of data smoothing method is not so important.

In case of short-term or weak factors, significant mean relative cumulative additional annual increment is rarely observed (Fig. 1.5). Regular significant value of increment was observed only in case of strong and permanent factors (Fig. 1.6). Short-term climatic factors were almost non-essential. Therefore this method can be used to certain detection of any factor.

1.2.9. Characterization of growth changes

For 40 sample sites selected across territory of Latvia with last year of growth 1995 or later, a number of years with significant mean relative cumulative additional annual increment was calculated for time periods from 1975 to 1984 (Fig. 1.7) and from 1985 to 1994 (Fig. 1.8).

In most of the sample sites, negative mean relative cumulative additional annual increment was found (31 sites at the first time period, and 33 – at second). Only in few sites it was positive (9 and 7 accordingly).

However, negative significant increment was found in 14 sample sites at the first time period, and 17 – at second. Positive significant increment was found only in one site at both time periods. Moreover, permanent significant increment (more than five years within ten year period) was found only in five at first and in ten sample sites at second time period. Therefore, it can be concluded that long-last significant mean relative cumulative additional annual increment can be found relatively infrequently. If permanent significant increment is found in many sample sites within certain territory, conclusion about presence of strong factor can be assumed.

Such analysis can help to locate territory with possible influence of permanent and strong factor. However, the assumptions on the character of factor cannot be performed. In this case, large-scale studies using more sample plots within particular territory must be carried out.

Permanent significant negative increment was found in sample site "8D35" near Ezere in both time periods. In this site, influence of industrial pollution of Mazeikiai oil refinery has been found with other methods – bioindication (Magone u.c. 1992) and chemical analysis (Nikodemus, Brūmelis 1998). Possibly, the decrease of tree growth was also related to pollution.

To assume the possible influence of Skrunda Radiolocation Station (SRL) on tree growth, large-scale studies have been performed. Possible influence of electromagnetic radiation of SRL on living organisms has been shown with several methods (Balode 1996; Detlavs et al. 1996; Kolodynski, Kolodynska 1996; Magone 1996; Selga, Selga 1996). This assumption was confirmed also with studies of tree growth increment (Balodis et al. 1996).

Significant negative mean relative cumulative additional annual increment was found in 20 of 24 sample sites in vicinity of Skrunda town. Long-lasting (more than five years) significant negative increment was found in 17 sample sites. This proportion was substantially larger than in other sample sites selected across the territory of Latvia and indicate possible influence of certain factor.

Significant negative increment was found in all seven plots affected by strong electromagnetic radiation and possibly it indicates the impact of Skrunda Radiolocation Station.

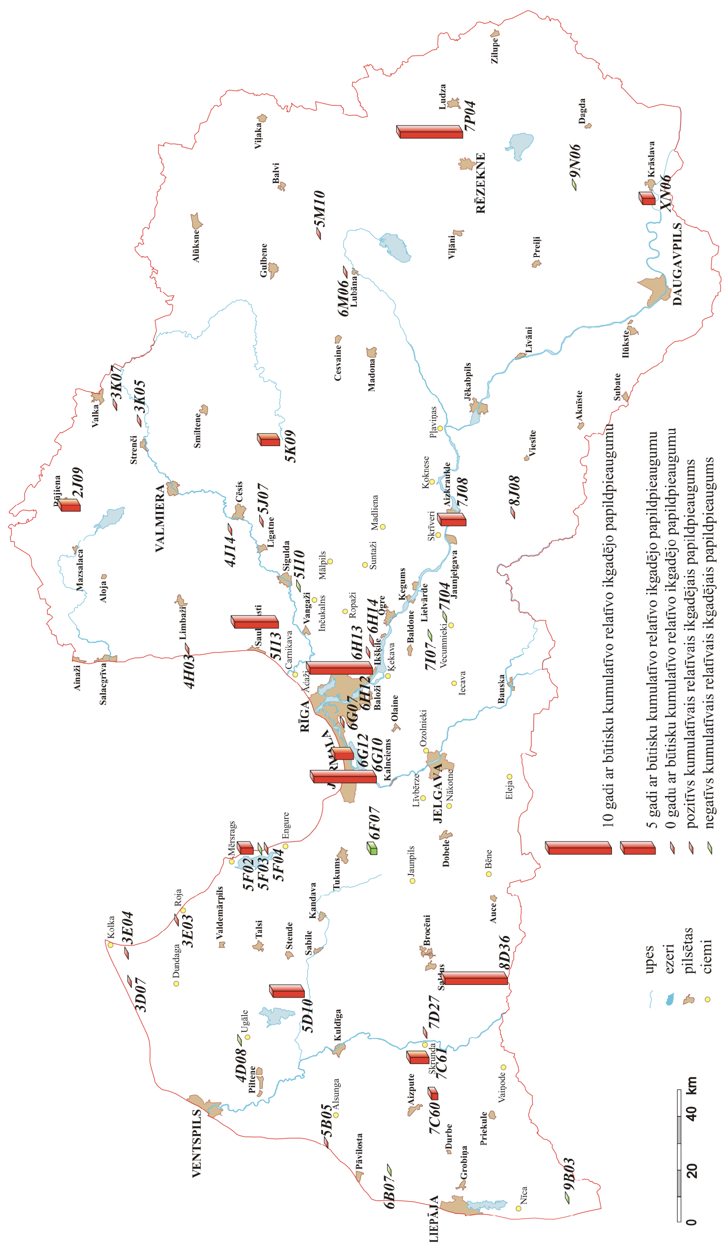

Figure 1.7. Number of years with significant ($p \leq 0.05$) mean relative cumulative additional increment within time period from 1975 to 1984 years. Only plots with data collection in 1995 year and later are shown. Cubic-smoothing spline with 11-year filter length and logarithmic data transformation were used. Green bars indicate positive additional increment, red bars – negative

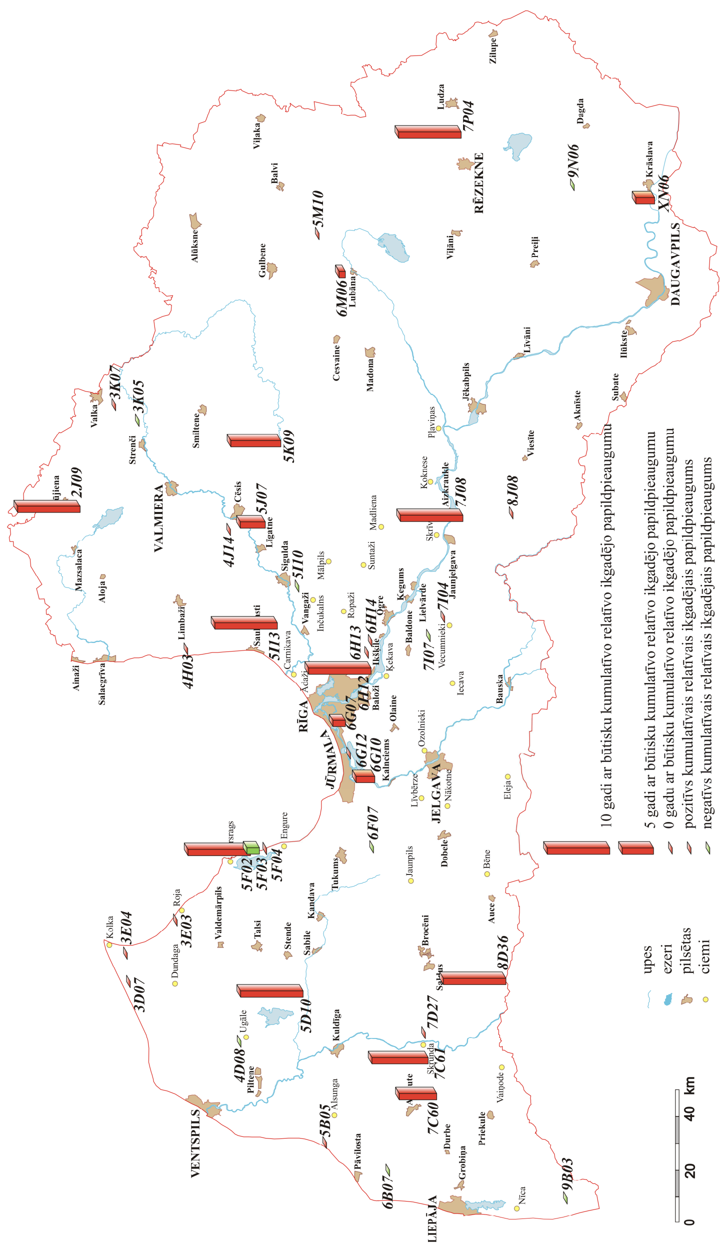

Figure 1.8. Number of years with significant ($p \leq 0.05$) mean relative cumulative additional increment within time period from 1985 to 1994. Only plots with data collection in 1995 year and later are shown. Cubic-smoothing spline with 11-year filter length and logarithmic data transformation were used. Green bars indicate positive additional increment. red bars – negative.

2. Conclusions

1. A new method for the detection of missing and false tree-rings was developed. Although this method is not sufficiently effective for the direct correction of tree-ring series, it can significantly improve the visual location of misdating rings.

2. The best-fitted models for Scots pine tree-ring width series were generalised exponential, negative exponential, and power models. These models can be linearized with logarithmical transformation, therefore logarithmic transformation should be applied before the use of parametric methods.

3. By logarithmic transformation, decrease of mean-to-standard deviation relationship of tree-ring width series can be achieved. Even greater decrease is achieved if a small constant is added before the transformation.

4. After 30 years, age-related factors become insignificant for Scots pine trees. Therefore, persistent significant tree growth changes indicate the presence of non age-related factors.

5. Test power for calculation of mean relative additional annual increment was highest when cubic-smoothing spline was used; however method selection possibly must be based also on the properties of analysed factor.

6. Relative cumulative additional increment is the best tool for the evaluation of the influence of strong and permanent factors. The highest test power can be achieved with use of cubic-smoothing spline.

7. If polynomial smoothing was used or smoothing was not applied, higher test power was obtained by adding a constant before logarithmic transformation. In case of cubic-smoothing spline, the use of simple logarithmic transformation is recommended.

8. If permanent significant increment is found in several sample sites within a certain territory, conclusion about presence of strong factor can be assumed.

9. Permanent significant mean relative cumulative additional annual increment was characteristic in most of the sample sites near Skrunda town, for data series after year 1975. It indicates the influence of strong factor; possibly it is impact of electromagnetic radiation emitted by Skrunda radiolocation station.

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