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CLIMATE—RADIAL INCREMENT RELATIONSHIPS IN ESTONIAN CONIFER STANDS

Abstract. Air pollution stress in conifer stands has become a world-wide problem in recent decades. This study deals with radial increment—climate relationships using about 70-year data from ten permanent forest plots and four meteorological stations. 15—50 dominant conifer trees were bored per plot and the smoothed growth curve and growth index I_d were found. The growth index I_d was subjected to stepwise regression against temperature and precipitation variables of the current and the previous hydrological year.

The effect of temperature and precipitation on the radial growth was found to be lower than 40% of the total variance. The sum of January and summer temperatures and precipitation sum in spring and autumn showed the strongest influence among climate factors of the current hydrological year. The most significant factors of the previous hydrological year were precipitation sums of January and the whole autumn period.

The detection of pollution stress on growth was not possible in our case.

Key words: Norway spruce, Scots pine, radial growth, climate, air pollution.

Introduction

Age and climate are the main factors influencing the radial growth in trees (Битвинскас, 1974). The climate—growth relationships have been investigated by European and American scientists since 1850. Annual growth has been found to correlate strongly with precipitation and temperature variables (Cook and Jacoby, 1977; Fritts, 1976). In northern forests the influence of the temperature of the growing season and the effect of summer temperatures in particular overshadow the other environmental factors (Eckstein, 1972). At extremely dry sites the growth of the cell wall is limited mainly by precipitation of the growing period. The annual ring width is directly related to climatic conditions of the preceding year. The earlywood width is more strongly influenced by the climate of the previous year than the latewood width (Fritts, 1976; Läänelaid and Lõhmus, 1986).

Federer et al. (1989) showed that the diameter growth in red spruce depends very little, if at all, on the temperature and precipitation of the growing season.

According to Juknis (Юкнис, 1990), Federer et al. (1989), Fritts (1976), McLaughlin et al. (1987), and Arp and Manasc (1988) the main climatic factors influencing radial growth are late winter and summer temperatures and the summer precipitation of the current year. Autumn temperatures have most powerful influence among the climatic variables of the previous year.

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In recent years the problem of radial growth connected with global climatic change and air pollution impact has become increasingly acute. Eckstein and Krause (1989) suppose that old trees have become ever more dependent on climate and this dependence cannot be explained by their age. It can be assumed that an additional influence of nonclimatic origin has occurred. Cook and Johnsson (1989), on the contrary, state that there has been a loss of climatic response in red spruce growth after about 1960 when air pollution effects became more evident.

Changing climate appears to alter the established patterns of phenology, carbon allocation, and frost-hardening, making the tree more susceptible to damage by short-term climate extremes and by air pollution.

Material and Methods

Radial growth data from 10 permanent plots in middle-aged and old Norway spruce and Scots pine stands and climatic data from four meteorological stations in Estonia were used in this study (Fig. 1; Table). In several cases we could not use the climatic data of the nearest to the sample plot meteorological station, as their observation sequences were not long or complete enough.

In each plot radial increment samples were bored from 15—50 dominant and codominant trees, one core per tree at breast height. Each growth curve is based on the radial growth data of 15—30 sample trees. The influence of the stand age was eliminated by standardization. For this aim the smoothing curve was found by means of moving averages of 23 years (11 years from both sides). The growth index was found for each year dividing the actual annual radial growth to the radial growth predicted by the smoothed curve:

$$I_{di} = \frac{j_{zi}\ \text{actual}}{j_{zi}\ \text{predicted}},$$

where I_d is the radial growth index, i — the year, and j_{zi} — radial growth in the year i.

Data on climate were available since 1921 (or 1925). The daily mean temperatures and precipitation amounts were summed up and the monthly sums of temperatures and precipitation were found. The annual sums of temperatures and precipitation were found as well.

The growth index I_{di} was subjected to stepwise regression analysis against all temperature and precipitation variables of the current and the previous hydrological year (September 1 — August 31). The correlation coefficients, regression equations, and significance level (P), determination coefficient (R^2), and standard error of estimate (S.E.E.) were calculated. The changes in the correlation during stand development were found by means of partitioning the growth and climate series into 9—10 year parts. The correlation coefficients were found using multivariate regression analysis.

The regression models were constructed for earlywood, latewood, and total annual ring width using the most frequent climate variables from regression equations.

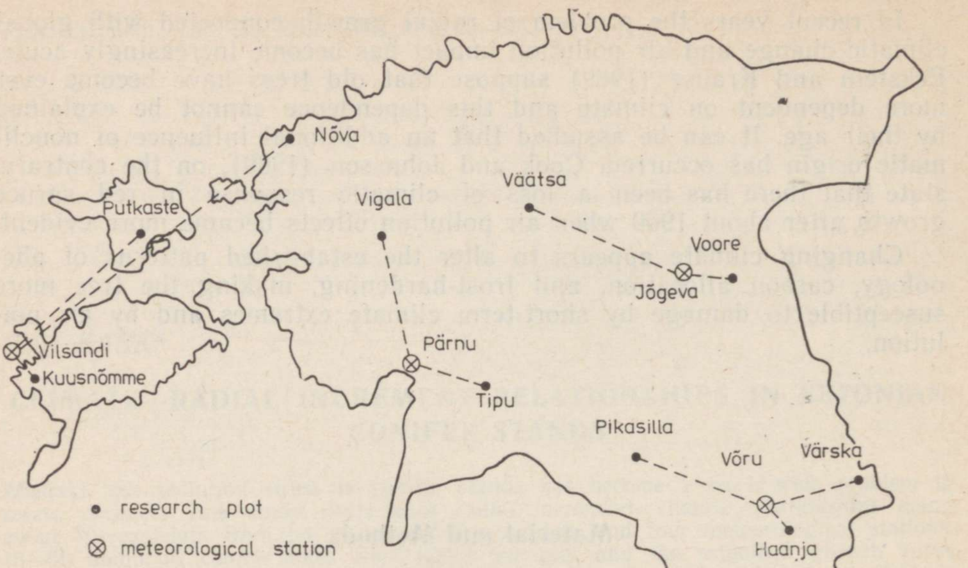

Fig. 1. Location of research plots and meteorological stations.

Data of permanent plots

Plot	Species	Mean age $\pm m_x$	Number of sample trees	Site quality class
Voore	spruce	47±2.6	21	I
Haanja	spruce	47±2.0	20	I
Väätsa	spruce	66±1.3	15	I
Vigala	spruce	43±0,6	24	I
	pine	44±0.8	25	I
Putkaste	spruce	66±4.6	19	II
	pine	71±2.2	20	
Kuusnõmme	spruce	87±6.4	11	IV, V
	pine	90±4.6	15	IV, V
Tipu	spruce	59±1.0	18	I
	pine	51±1.1	22	I
Pikasilla	spruce	70±1.9	29	III
	pine	64±0.7	18	III
Nõva I	pine	147±4.7	24	V
Nõva II	pine	84±4.7	17	V
Värska	pine	54±1.4	24	III

Results and Discussion

Temperature and precipitation determine up to 42% of the total variance in the radial increment of spruce and pine stems. The rest is determined by the age, competition, and other environmental variables.

Regression models of the radial growth of spruce stands are the following ($P<0.05$—0.001; $R^2=0.09$—0.40; S.E.$=0.05$—0.22):

A. Earlywood width:

$$Y=T_{\mathrm{Jan}\ cy}-T_{\mathrm{Summer}\ cy}+P_{\mathrm{Spring}\ cy}+T_{\mathrm{July}\ py}+P_{\mathrm{Sum}\ py}+b.$$

B. Latewood width:

$$Y=T_{\mathrm{Jan}\ cy}-T_{\mathrm{Summer}\ cy}-T_{\mathrm{Autumn}\ cy}+P_{\mathrm{Jan}\ cy}-P_{\mathrm{Apr}\ cy}+P_{\mathrm{Autumn}\ cy}+ +P_{\mathrm{Jan}\ py}+P_{\mathrm{Spring}\ py}+b.$$

C. Total width of an annual ring:

$$Y=T_{\mathrm{Jan}\ cy}+P_{\mathrm{Autumn}\ cy}+T_{\mathrm{Spring}\ py}+P_{\mathrm{Autumn}\ py}+b,$$

where T is temperature, P — precipitation, cy — current hydrological year, py — previous hydrological year, and b — constant.

Regression models of the radial growth of pine stands are the following ($P<0.05$—0.001; $R^2=0.08$—0.42; S.E.$=0.05$—0.20):

A. Earlywood width:

$$Y=T_{\mathrm{Jan}\ cy}+T_{\mathrm{Autumn}\ cy}+P_{\mathrm{May}\ cy}+P_{\mathrm{Sum}\ cy}-T_{\mathrm{Summer}\ py}+P_{\mathrm{May}\ py}+b.$$

B. Latewood width:

$$Y=T_{\mathrm{March}\ cy}-T_{\mathrm{Summer}\ cy}+T_{\mathrm{Sum}\ cy}+P_{\mathrm{May}\ cy}+P_{\mathrm{Sum}\ cy}+T_{\mathrm{March}\ py}+ +T_{\mathrm{Aug}\ py}+P_{\mathrm{June}\ py}+b.$$

C. Total width of an annual ring:

$$Y=T_{\mathrm{Jan}\ cy}+T_{\mathrm{Apr}\ cy}-T_{\mathrm{Summer}\ cy}+P_{\mathrm{Spring}\ cy}+P_{\mathrm{Autumn}\ py}+T_{\mathrm{July}\ py}+ +P_{\mathrm{May}\ py}+b.$$

The sum of January temperatures influenced the radial growth significantly. The other winter characteristics did not show any significant correlation. The effect of January temperatures may be explained by the fact that in low temperatures trees may require stored carbohydrates to survive, which reduces the next year's growth.

The strong influence of high temperatures of the current summer and autumn that reduced radial growth can be explained by the associated water deficit.

High temperatures of the previous summer reduce the amount of stored carbohydrates affecting diameter growth the next year.

Schweingruber et al. (1979) found that high temperatures in April are favourable to intensive thickening of cell walls. The hormones necessary for radial growth form during this period. The positive effect of high April temperatures on radial increment was confirmed by this study, too. High temperatures in May and June had not any pronounced effect on the cell wall development.

Precipitation of the previous autumn and the current spring replenishes soil moisture deposits which affect the growth in spring. The weather of the previous year affects the ring width also during the following years through the effects on buds and the growth of leaves, roots, and fruits. The current production is influenced by the amount of precipitation in January, spring, and autumn as well as by the temperature during the spring and summer of the previous hydrological year.

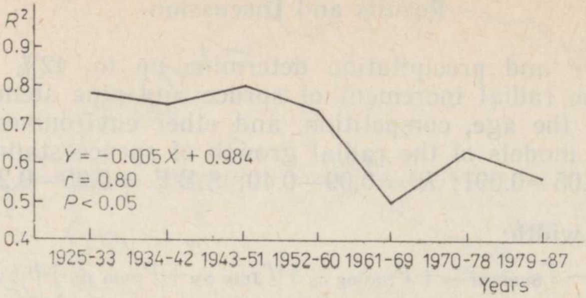

Fig. 2. Correlation between radial increment and climate during stand development in Pikasilla plot (Scots pine).

The correlation of current growth with the weather of the autumn the year before the previous year was very low. In general the weather characteristics of the previous hydrological year had lower influence on the radial growth of the current year than the weather characteristics of the current hydrological year.

Earlywood width in pine is more strongly determined by the preceding autumn and the current spring weather, while latewood width is affected by the current spring and summer. In spruce stands earlywood production is determined more strongly by factors of the current hydrological year, while latewood width is closely related to factors of the preceding hydrological year. Climatic factors of the previous hydrological year influence the total annual ring width in spruce more notably than in pine. The number of different climatic factors affecting radial growth in spruce is smaller than those in pine, but the duration of their influence is longer.

The relationships between radial increment and climate are not constant during stand development. Unfortunately, the correlations between 10-year growth periods and climate variables were statistically significant only in a few cases, though there was significant correlation for complete series. The correlation trends during stand development are not similar for all stands. It is evident that in 1960—1969 the correlation was either the lowest (in most cases) or had its peak. A statistically significant decrease in correlation in the pine stand (Fig. 2) occurred only in the Pikasilla plot, but in a spruce stand in the same location it was absent, so pollution influence on climate—growth relationships was not verified.

Conclusions

The role of total monthly temperatures and precipitation in determining the radial growth in Scots pine and Norway spruce was found to be lower than 40% of the total variance. Low temperatures in January and high temperatures in summer and the precipitation amount in spring and autumn showed the strongest influence among the climatic factors of the current hydrological year. The most significant factors of the previous hydrological year were precipitation sums of January and the whole autumn period. In general the factors of the previous hydrological year had a minor influence. Correlations between diameter growth and climate were not constant in stand ontogeny and therefore we did not find any pollution stress on radial growth through the climatic model.

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