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ASSESSMENT OF THE ROLE OF CLIMATE CHANGE IN RECENT RADIAL INCREMENT INCREASE OF *PICEA ABIES* AND *PINUS SYLVESTRIS*

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Abstract. This study was carried out on the basis of growth date from ten permanent plots and climate data from four meteorological stations in Estonia. The growth—climate regression model was calibrated up to 1987; for the years 1982—91 both the actual growth indices and those calculated from the regression model were found.

Although pollution loads are rather high and the damage of crowns and roots is evident, the mean radial growth shows generally an increasing trend. It was concluded that the competition of trees had no effect on radial increment. Climatic conditions, especially January temperatures, were very favourable for growth. No statistically significant difference was found between the actual growth and that calculated from the climate model. The increase of growth—climate synchronism suggests that the increment of radial growth in recent years has been possible thanks to favourable climatic conditions. The effect of fertilization due to environmental pollution was not verified.

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

INTRODUCTION

Climate affects tree growth directly through the crown (photosynthesis and respiration) and the root system (water and nutrient uptake); therefore, there is some potential for incorporating climate data into predictions of growth and yield (Robertson et al., 1990). The annual radial growth of a tree growing under natural conditions tends to increase rapidly till it reaches a maximum, thereafter it begins to decline, first rather rapidly and then at a slower rate. The age at which the tree reaches the culmination of growth depends on many factors, e. g. species, site quality, competition among trees (Thammincha, 1981).

In order to directly quantify the influence of pollution on tree growth, sufficiently long-term series of pollution data are necessary. However, pollution measurements have been recorded for only a few years. Therefore, instead of the missing pollution data the production data of factories are sometimes used as proxy data in the growth model. Where proxy data are also lacking, a dendroclimatological approach has been applied in several studies. Actually measured and artificially constructed tree ring widths can be compared and deviations of both tree ring series from each other interpreted (Eckstein, 1985; Юкнис, 1990). In most cases the degree of the suppression of radial growth observed is greater than would be expected on the basis of previous growth—climate relationships. This relationship between growth and climate suggests either the influence of recent unique combinations of climatic stresses or a possible interactive intervention of other region-scale stresses, such as atmospheric pollution (McLaughlin et al., 1987; LeBlank et al., 1987; Eckstein & Krause, 1989).

It has also been shown that a certain level of pollution, especially the deposition of nitrogen on poor soils or trees with an insufficient nutrient supply, may increase increment, while pollution above a certain level may damage the tree and lead to its reduced growth. Such effects may differ from one individual tree to another in the same stand (Steinlin, 1985; Aber et al., 1989).

Last but not least, the changing of climate itself may have disrupted the established patterns of phenology, carbon allocation, and freeze hardening, thus making the tree more susceptible to damage from short-term climatic extremes, such as frost damage and chronic exposures to atmospheric pollutants (Cook & Johnson, 1989).

The aim of this study was to assess the increase of recent radial increment and its connection with climate changes.

MATERIALS AND METHODS

This study was carried out on radial growth data collected from ten permanent forest sample plots and climate data from four meteorological stations (see the location of these in Kask, 1992; and Kask & Frey, 1993). General data on the stands investigated, including soil analyses, have also been published earlier (Kask, 1992; Frey et al., 1992; Lõhmus & Lasn, 1991).

On each plot radial increment samples were bored at breast height from 15—50 dominant or codominant trees. Each long-term growth data scale is based on the data of 15—30 sample trees.

Data on climate were available since 1921 (or 1925). Among all climate variables the monthly mean temperature and precipitation of the current and previous hydrological (1 Sept.—31 Aug.) years as the main factors influencing growth were studied. The sums of temperatures, negative temperatures, and precipitation of the current and previous hydrological years were also included in the study. The regression model was found using stepwise regression analysis for the data scale of 63—67 years, so the model was calibrated up to the year 1987. For the years 1982—91 both indices were found: the actual index based on the moving averages of 20—11 years and the calculated one found from the radial growth—climate regression models. The actual annual indices were calculated using the means of the following years:

1982: 1972—91 (20 years);
1983: 1973—91 (19 years);

1991: 1981—91 (11 years).

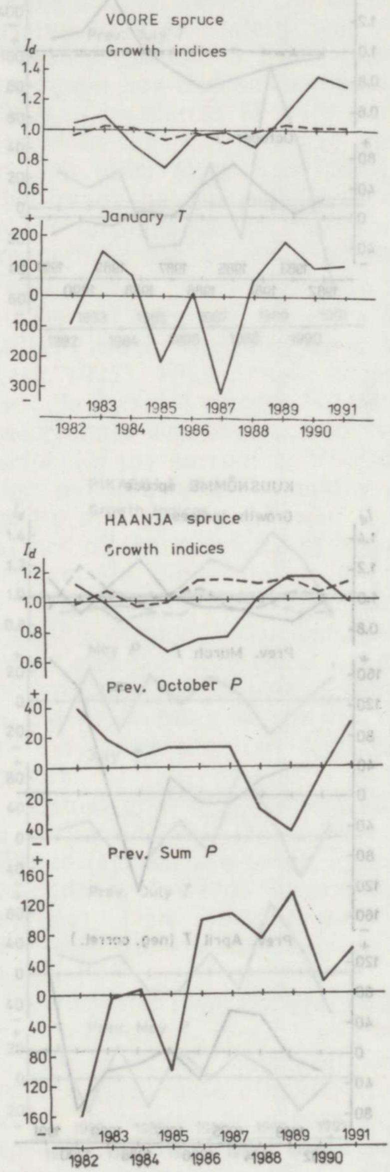
The calculated index was found with the help of statistically significant climatic variables of the long-scale model only. The absolute climate fluctuations for 1982—91 were likewise established by applying the moving averages of 20—11 years.

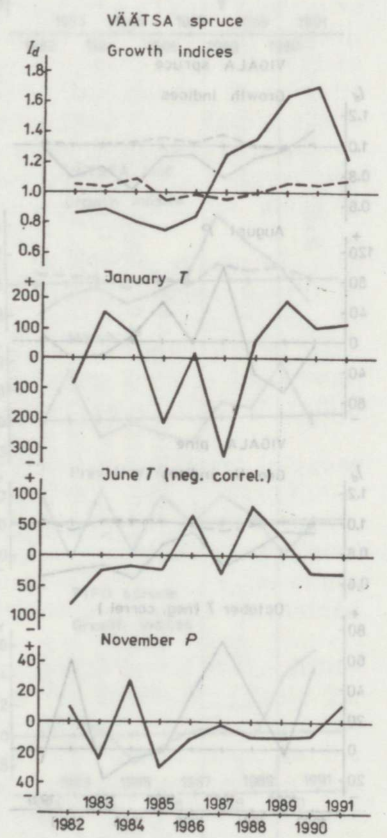
The synchronism index (Битвинскас, 1974) was found for the establishment of radial growth indices and climate synchronism. The index was estimated as the percentage of climate fluctuations occurring in the same direction from the mean as the radial growth index. The synchronism index was found between the radial growth indices and climate data according to regression equations for the years 1982—91. In case more than one climate factor affected growth, the mean synchronism index was used.

$$C_x = n^{+} \times 100/N-1,$$

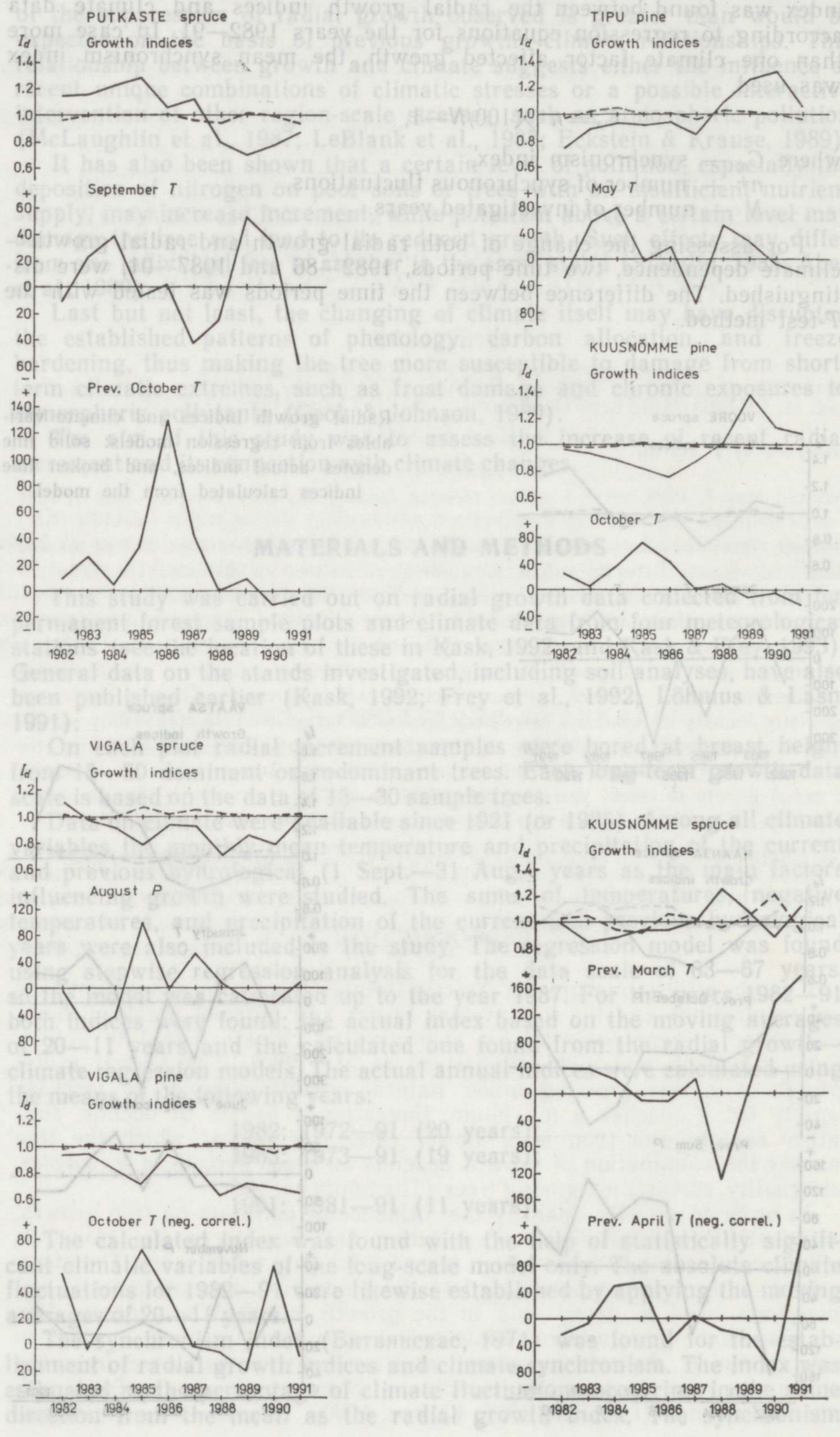
where C_x — synchronism index,
n^{+} — number of synchronous fluctuations,
N — number of investigated years.

For assessing the change of both radial growth and radial growth—climate dependence, two time periods, 1982—86 and 1987—91, were distinguished. The difference between the time periods was tested with the T-test method.





Radial growth indices and climate variables from regression models: solid line denotes actual indices, and broken line indices calculated from the model.


PUTKASTE spruce
Growth indices
September T
Prev. October T
VIGALA spruce
Growth indices
August P
VIGALA pine
Growth indices
October T (neg. correl.)
TIPU pine
Growth indices
May T
KUUSNÕMME pine
Growth indices
October T
KUUSNÕMME spruce
Growth indices
Prev. March T
Prev. April T (neg. correl.)
I_d
1982
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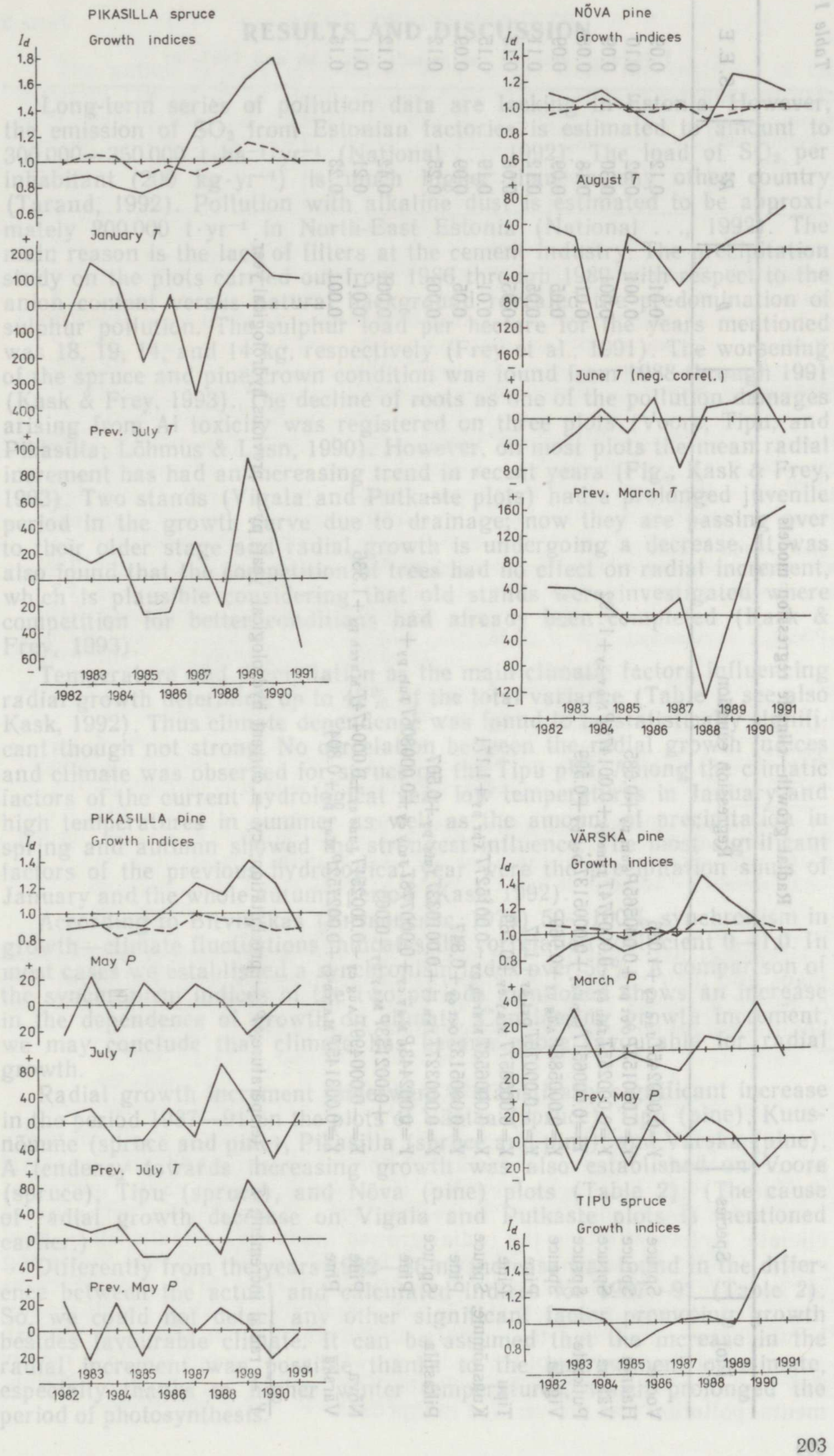
PIKASILLA spruce
Growth indices
I_d
January T
Prev. July T
PIKASILLA pine
Growth indices
I_d
May P
July T
Prev. July T
Prev. May P
NÕVA pine
Growth indices
I_d
August T
June T (neg. correl.)
Prev. March T
VÄRSKA pine
Growth indices
I_d
March P
Prev. May P
TIPU spruce
Growth indices
I_d
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991

Table 1

Radial growth—climate regression models

Plot	Species	Regression equation	p	R^2	S. E. E
Voore	Spruce	$Y=0.000245T_{\text{Jan cy}}+1.036$	0.01	0.12	0.09
Haanja	Spruce	$Y=0.000153P_{\text{Oct py}}+0.000565P_{\text{Sum py}}+0.685$	0.001	0.32	0.10
Väätsa	Spruce	$Y=0.000255T_{\text{Jan cy}}-0.000474T_{\text{June cy}}+0.001479P_{\text{Nov cy}}+1.192$	0.001	0.30	0.09
Putkaste	Spruce	$Y=0.000651T_{\text{Sept cy}}+0.000513T_{\text{Oct py}}+0.599$	0.01	0.18	0.08
Vigala	Spruce	$Y=0.000588P_{\text{Aug cy}}+0.969$	0.05	0.09	0.09
	Pine	$Y=-0.00076T_{\text{Oct cy}}+1.17$	0.05	0.12	0.11
Tipu	Pine	$Y=0.000657T_{\text{May cy}}+0.769$	0.05	0.08	0.13
Kuusnõmme	Spruce	$Y=0.000658T_{\text{March py}}-0.001527T_{\text{Apr py}}+1.171$	0.01	0.19	0.15
	Pine	$Y=0.000513T_{\text{Oct cy}}+0.847$	0.05	0.09	0.09
Pikasilla	Spruce	$Y=0.000327T_{\text{Jan cy}}+0.001033T_{\text{July py}}+0.507$	0.001	0.25	0.12
	Pine	$Y=0.002443P_{\text{May cy}}+0.000778T_{\text{July cy}}+0.000806T_{\text{July py}}+$ $+0.002153P_{\text{May py}}-0.065$	0.001	0.42	0.12
Nõva	Pine	$Y=-0.000499T_{\text{Aug cy}}-0.000251T_{\text{June cy}}+0.000474T_{\text{March py}}+1.336$	0.01	0.21	0.11
Värska	Pine	$Y=0.003145P_{\text{March cy}}+0.002752P_{\text{May py}}+0.804$	0.001	0.23	0.15

Y — radial increment; T — temperature; P — precipitation; cy — current hydrological year; py — previous hydrological year.

RESULTS AND DISCUSSION

Long-term series of pollution data are lacking in Estonia. However, the emission of SO_2 from Estonian factories is estimated to amount to 300 000—350 000 $t \cdot ha^{-1} \cdot yr^{-1}$ (National ..., 1992). The load of SO_2 per inhabitant (200 $kg \cdot yr^{-1}$) is much higher than in any other country (Tarand, 1992). Pollution with alkaline dust is estimated to be approximately 200 000 $t \cdot yr^{-1}$ in North-East Estonia (National ..., 1992). The main reason is the lack of filters at the cement industry. The precipitation study on the plots carried out from 1986 through 1989 with respect to the anion content versus natural background revealed the predomination of sulphur pollution. The sulphur load per hectare for the years mentioned was 18, 19, 14, and 14 kg, respectively (Frey et al., 1991). The worsening of the spruce and pine crown condition was found from 1988 through 1991 (Kask & Frey, 1993). The decline of roots as one of the pollution damages arising from Al toxicity was registered on three plots (Voore, Tipu, and Pikasilla; Lõhmus & Lasn, 1990). However, on most plots the mean radial increment has had an increasing trend in recent years (Fig.; Kask & Frey, 1993). Two stands (Vigala and Putkaste plots) had a prolonged juvenile period in the growth curve due to drainage; now they are passing over to their older stage and radial growth is undergoing a decrease. It was also found that the competition of trees had no effect on radial increment, which is plausible considering that old stands were investigated where competition for better conditions had already been completed (Kask & Frey, 1993).

Temperature and precipitation as the main climatic factors influencing radial growth determine up to 42% of the total variance (Table 1; see also Kask, 1992). Thus climate dependence was found to be statistically significant though not strong. No correlation between the radial growth indices and climate was observed for spruce on the Tipu plot. Among the climatic factors of the current hydrological year low temperatures in January and high temperatures in summer as well as the amount of precipitation in spring and autumn showed the strongest influence. The most significant factors of the previous hydrological year were the precipitation sums of January and the whole autumn period (Kask, 1992).

According to Bitvinskas (Битвинскас, 1974) 50—100% synchronism in growth—climate fluctuations indicates the correlation coefficient 0—1.0. In most cases we established a synchronism index over 50%. A comparison of the synchronism indices of the two periods mentioned shows an increase in the dependence of growth on climate. Considering growth increment, we may conclude that climate has become more favourable for radial growth.

Radial growth increment underwent a statistically significant increase in the period 1987—91 on the plots of Väätsa (spruce), Tipu (pine), Kuusnõmme (spruce and pine), Pikasilla (spruce and pine), and Värska (pine). A tendency towards increasing growth was also established on Voore (spruce), Tipu (spruce), and Nõva (pine) plots (Table 2). (The cause of radial growth decrease on Vigala and Putkaste plots is mentioned earlier.)

Differently from the years 1982—86 no increase was found in the difference between the actual and calculated indices for 1987—91 (Table 2). So, we could not detect any other significant factor promoting growth besides favourable climate. It can be assumed that the increase in the radial increment was possible thanks to the improvement of climate, especially thanks to higher winter temperatures, which prolonged the period of photosynthesis.

Table 2

Difference between the periods 1982—86 and 1987—91

Permanent plot	Species	Synchronism index, % 1982—86	Synchronism index, % 1987—91	T_1	T_2	T_3
Voore	Spruce	50	100	—	—	—
Haanja	Spruce	25	38	—	—	—
Väätsa	Spruce	50	67	−7.6 ($p<0.001$)	4.3 ($p<0.01$)	5.8 ($p<0.001$)
Putkaste	Spruce	88	75	4.3 ($p<0.01$)	—	−3.9 ($p<0.01$)
Vigala	Spruce	75	50	—	−3.5 ($p<0.01$)	—
	Pine	100	25	−2.9 ($p<0.05$)	−6.8 ($p>0.001$)	−2.6 ($p<0.05$)
Tipu	Spruce	—	—	—	—	—
	Pine	50	75	−4.4 ($p<0.01$)	—	2.5 ($p<0.05$)
Kuusnõmme	Spruce	50	57	−2.5 ($p<0.05$)	—	2.4 ($p<0.05$)
	Pine	0	25	−2.8 ($p<0.05$)	—	2.3 ($p<0.05$)
Pikasilla	Spruce	50	88	−7.2 ($p<0.001$)	6.4 ($p<0.001$)	4.3 ($p<0.01$)
	Pine	56	69	—	3.0 ($p<0.05$)	2.5 ($p<0.05$)
Nõva	Pine	96	92	—	—	—
Värska	Pine	75	100	−3.8 ($p<0.01$)	—	2.3 ($p<0.05$)

T_1 — difference between actual and calculated 1982—86 indices;
T_2 — difference between actual and calculated 1987—91 indices;
T_3 — difference between actual 1982—86 and actual 1987—91 indices;
— no correlation with climate found.

Further investigations are needed for the determination of pollution loads and their spatial and temporal variation in Estonia. The hypothesis of Steinlin (1985) and Aber et al. (1989) about the fertilization effect of environmental pollution was not verified in this case.

CONCLUSIONS

In comparison with other countries pollution in Estonia has been heavy in recent years. A general decline of conifer crowns, and an occasional decline of roots have been recorded. However, the mean radial increment has had a increasing trend in recent years. Synchronism between the climatic factors affecting the radial growth index was established in most cases. This index is generally greater for the period 1987—91 indicating an increase of the dependence of growth on climate. Still, in most cases the radial growth increased also in the recent period, while the difference between the actual and the calculated growth did not increase. We can assume that the increase of the radial growth in the recent period is mostly due to the improvement of the climate. The fertilization effect of environmental pollution was not verified in this case.

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REFERENCES

Aber, J. D., Nadelhoffer, K. J., Steudler, P., Melillo, J. M. 1989. Nitrogen saturation in northern forest ecosystems. — Bioscience, 39, 6, 378—386.

Cook, E. R., Johnson, A. H. 1989. Climate change and forest decline: A review of the red spruce case. — Water, Air and Soil Pollution, 48, 127—140.

Eckstein, D. 1985. On the application of dendrochronology for the evaluation of forest damage. — In: Inventoring and Monitoring Endangered Forests. IUFRO Conference, Zürich, 1985, 287—290.

Eckstein, D., Krause, C. 1989. Dendroecological studies on spruce trees to monitor environmental changes around Hamburg. — IAWA Bulletin, 10, 2, 175—182.

Frey, J., Frey, T., Rästa, E. 1991. Sademete saastatusest Eestis 1986—1989. — In: Kaasaegse ökoloogia probleemid. Ökoloogia ja energeetika. Eesti V ökoloogiakonverentsi teesid, Tartu, 24.—26. aprill 1991, 25—29.

Frey, T., Frey, J., Lõhmus, K., Kask, P. 1992. Esialgseid tulemusi metsade seisundi hindamisel püsiproovialadel. — In: Õrd, A. (ed.). Eesti metsade kaitse ja kasutamine. Tallinn, 74—95.

Kask, P. 1992. Climate—radial increment relationships in Estonian conifer stands. — Proc. Estonian Acad. Sci. Ecol., 2, 1, 22—27.

Kask, P., Frey, J. 1993. Vitality of Norway spruce and Scots pine by the crown class and radial increment in 1988—1991. — Proc. Estonian Acad. Sci. Ecol., 3, 1, 8—16.

LeBlank, D., Raynal, D. J., White, E. H. 1987. Acidic deposition and tree growth: Assessing the role of climate in recent growth declines. — J. Environ. Qual., 4, 334—340.

Lõhmus, K., Lasn, R. 1990. Spruce and pine root structures and chemical characteristics in moderate acid soils. — In: Persson, H. (ed.). Above- and Below-ground Interactions in Forest Trees in Acidified Soils. Air Pollution Research Report, 32, 74—78.

Lõhmus, K., Lasn, R. 1991. Alumiiniumi toksilisusest Eesti kuusikutes. — In: Kaasaegse ökoloogia probleemid. Ökoloogia ja energeetika. Eesti V ökoloogiakonverentsi teesid, Tartu, 24.—26. aprill, 1991, 98—101.

McLaughlin, S. B., Downing, D. J., Blasing, T. J., Cook, E. R., Adams, H. S. 1987. On the analysis of climate and competition contributors to decline of red spruce in high elevation Appalachian forests of the United States. — Oecologia, 72, 487—501.

National Report of Estonia to UNCED 1992. 1992. Ministry of the Environment, Tallinn.

Robertson, E. O., Jozsa, L. A., Spittlehouse, D. L. 1990. Estimating Douglas-fir wood production from soil and climate data. — Can. J. For. Res., 20, 357—364.

Steinlin, H. 1985. Possible effects of acid deposition on forest growth, removals and timber markets. — In: Symposium on the Effects of Air Pollution. Helsinki, April 23—24, 1985, 109—113.

Tarand, A. 1992. Energeetika teed ja eksiteed. — Eesti Loodus, 4, 197—201.

Thammincha, T. 1981. Climatic variation in radial growth of Scots pine and Norway spruce and its importance in growth estimation. — Acta Forestalia Fennica, 171.

Битвинскас Т. Т. 1974. Дендроклиматологические исследования. Гидрометеоиздат, Ленинград.

Юкнис Р. А. 1990. Рост и продуктивность одновозрастных сосняков в условиях загрязненной среды. Красноярск.

KUUSE JA MÄNNI RADIAALJUURDEKASVU VIIMASEL AASTAKÜMNEL MÕJUTANUD KLIIMAMUUTUSED

Priit KASK

Uurimus põhineb Eesti kümne prooviala puude radiaaljuurdekasvu ja nelja meteoroloogiajaama kliimaandmetel. Juurdekasvu ja kliima regressioonimudel kalibreeriti aastani 1987, aastateks 1982—1991 leiti nii tegelikud kui ka arvutuslikud kasvuindeksid. Kuigi saastekogused on üsna suured ja puude võrade ning juurte kahjustumine ilmne, on nende keskmine juurdekasv viimastel aastatel olnud jõudsam. Puude omavaheline konkurents ei ole radiaaljuurdekasvule mõju avaldanud. Kliimaolud, eriti jaanuari temperatuur, olid kasvuks väga soodsad. Statistiliselt usaldusväärne erinevus tegeliku juurdekasvu indeksi ja kliimamudelist arvutatu vahel puudus. Arvestades ka kliima ja juurdekasvu sünkroonsuse suurenemist, võib seostada radiaaljuurdekasvu intensiivistumist soodsate kliimatingimustega. Keskkonna saastumisega kaasneva väetamisefekti olemasolu ei olnud võimalik tõestada.

ВЛИЯНИЕ ИЗМЕНЕНИЯ КЛИМАТА НА РАДИАЛЬНЫЙ ПРИРОСТ У *PICEA ABIES* И *PINUS SYLVESTRIS*

Прийт КАСК

В настоящей работе изучены данные о радиальном приросте, полученные с 10 пробных участков, а также данные о климате, полученные с 4 метеостанций. Регрессионная модель калибрована до 1987 г., на годы 1982—1991 найдены фактические индексы прироста и рассчитаны с использованием регрессионной модели.

Несмотря на возрастающее повышение загрязненности среды, ухудшение состояния кроны и корней, средний радиальный прирост деревьев в последние годы повышается. Конкуренция между деревьями не оказала влияния на прирост. Климатические условия, особенно температура в январе, оказались очень благоприятными для радиального прироста. Статистически достоверной разницы между фактическими и рассчитанными по модели данными не обнаружено. Если учесть синхронность изменения климата и радиальнго прироста, то повышение радиального прироста можно объяснить благоприятностью климатических условий.