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GROWTH AND NEEDLE RETENTION OF SCOTS PINE TREES IN THE REGION OF OIL SHALE INDUSTRY

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The long-term impact of air pollutants emitted by oil shale industry on growth and needle retention in Scots pine (Pinus sylvestris L.) was examined at Kose, in the middle of the North-East Estonian industrial region. Control trees were chosen in a stand growing at Lehtmetsa, North Estonia, 130 km from Kose. At both sites, ten pine trees were felled and analysed for the height and radial growth rate, and needle retention by using the needle trace method. During the period of 1964–1997, the average height increment of the trees was 47 and 37 cm yr^{-1} *(*$P < 0.001$*) and the average radial increment 2.11 and 0.93 mm* yr^{-1} *(*$P < 0.001$*) at Kose and Lehtmetsa, respectively. The mean needle age was 2.0 and 2.1 years (*$P = 0.06$*), the mean number of needles on newly sprouted shoots was 266 and 228 (*$P < 0.001$*), and the average needle density was 5.9 and 9.1* cm^{-1} *(*$P < 0.001$*) at Kose and Lehtmetsa, respectively. Changes in concentrations of neither fly ash nor* SO_2 *caused variations in the growth of trees and needle retention at Kose.*

Introduction

The impact of air pollution on the health of forests has attracted both scientific and public attention since the middle of 1970s when widespread damages of forests occurred in Central Europe. The main symptoms of the

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forest decline ranged from needle yellowing and loss up to dying of trees and the whole stands [1]. Forest health surveys based on these symptoms were carried out in many countries, the first results of which led to changes in prevailing perceptions about forest decline [2]. It became evident that the knowledge of natural variability in crown condition and the growth parameters of healthy trees were rather scanty [2, 3]. Besides, the methods applied for forest health assessments were highly subjective – the same methods used by different researchers on the same trees gave often different results [3].

The most polluted area in Estonia is located in the northeastern part of the country, where the aggregation of oil shale industry has been responsible for the rise in concentrations of alkaline fly ash and SO_2, as well as NO_x, NH_3, H_2S, and organic compounds in the atmosphere [4–7]. As a result of the pollution, the condition of the coniferous forests in North-East Estonia worse than in other parts of the country, has been shown by forest survey projects [8–11]. However, there is no background data about forest health in North-East Estonia for the period before the increase in emission rates of the pollutants since the 1950s. This raises a question whether the forest health was actually better some decades ago. Also the reliability of methods for assessment of the forest condition applied by different researchers seems to be questionable. For example, in 1986, the condition of coniferous forests in this region has been estimated from good to satisfactory [12], but in another study [13] carried out four years later, it has been classified as unsatisfactory.

To overcome the shortcomings resulting from the lack of retrospective data on the forest condition in North-East Estonia, an investigation was initiated with the aim of obtaining the long-term data about needle retention and growth parameters of Scots pine trees. In this paper the first results of the investigation are given with emphasis on the question whether changes in the air pollution levels have had any impact on mean needle age, needle density, number of needles, and height and radial growth rate.

Study Area

Two Scots pine stands (Fig. 1), both at *Rhodococcum* site type [14], were chosen to compare the needle retention and growth chronologies during the last 30 years. Stand I was located at Kose, in the middle of the most polluted region in Estonia, approximately 7 km from the nearest air pollution source (Ahtme Power Plant). Stand II, taken as a control plot, was located at Lehtmetsa, North Estonia, far away from large air pollution sources. The distance between the study plots was about 130 km. The stand at Lehtmetsa is most probably a natural stand, whereas that at Kose was seeded by man.

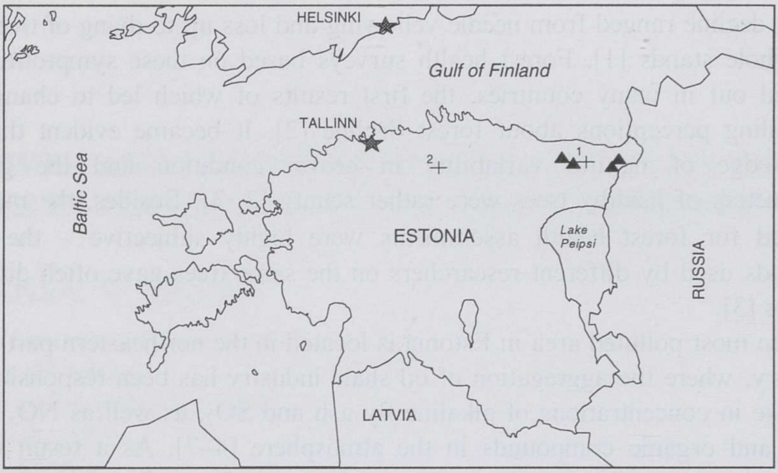

Fig. 1. Location of sample stands. *1* – Kose, *2* – Lehtmetsa, ▲ – power plants operating on oil shale

Materials and Methods

In both stands 10 pine trees were felled in the summer of 1998 according to the guidelines provided by Aalto and Jalkanen [15]. The sample trees belonged to the main storey, they had straight undamaged stems and their crowns were regular-shaped. The basic characteristics of the stands and sample trees are given in the Table. The sample trees were older at Lehtmetsa than at Kose. The initial purpose was, however, to obtain sample trees in corresponding stages of development because the leaf longevity may be affected by tree height.

Basic Information of Study Sites and Sample Trees

Stand	Location		Altitude, m a.s.l.	Forest site type	Age	Height, m	d.b.h., cm
	N	E					
Lehtmetsa	59° 12’	25° 35’	60	*Rhodococcum*	65	18.7	14.9
Kose	59° 19’	27° 32’	45	*Rhodococcum*	40	17.7	14.9

Before felling of the trees, the eastern side of the tree was marked on the stem. After felling, the mark of the compass direction was extended along the whole stem. On all trees, the number of needle sets was assessed by 25 % classes on the main stem and also on 3 to 5 branches from the 10th whorl from the top of the tree. Discs from each tree were cut at breast height (b.h.)

for subsequent measurements of radial increment. The parts of the stems above b.h. were sectioned into bolts corresponding to annual shoot increments, omitting the branch whorls as instructed by Aalto and Jalkanen [15]. The whole lengths of the increments were previously recorded. However, the youngest part of the stems (the last 5–9 years) were kept intact while they were transported to the laboratory.

In the laboratory, the calendar year of the shoot initiation was marked on each annual bolt and the angles of 40–45° at the ends of the bolt. The bolts were planed tree ring by tree ring, handling from outside inside, the legs of the angles at the opposite bolt's ends were joined with lines, and the number of needle traces within the rectangular formed at the planed surface of the 5–6 innermost tree rings was recorded. Thus, it was assumed that the age of the oldest needles would not exceed 6 years. The needle trace data was used to calculate the needle degree (relative number of needles) of annual shoots:

$$ND_r = \frac{x_r}{x_1} \qquad (1)$$

where ND_r is the needle degree in a specific shoot's annual ring r;

x_r is the number of needle traces in the annual ring r;

x_1 is the number of needle traces in the first annual ring.

The needle retention of the trees was characterised by the mean needle age:

$$NA = \sum_{r=1}^{n} (ND_r - ND_{r+1})(r - 1 + \frac{t}{12}) \qquad (2)$$

where NA is the average age of the needles born in a certain year;

ND_r is the shoot's needle degree in annual ring r;

ND_{r+1} is the shoot's needle degree in the next annual ring;

r is the sequence number of the growth ring from the pith;

t is the interval between budbreak and yellowing of senescent needles in months.

The density and number of needles formed in a certain year were calculated as well:

$$ND = \frac{360^\circ x}{\alpha \cdot l_b} \qquad (3)$$

where ND is the needle density (cm^{-1});

x is the number of needle traces in the innermost annual ring of the bolt;

α is the mean of angles at the ends of the bolt;

l_b is the bolt length.

$$NN = ND \cdot l_s \qquad (4)$$

where NN is the number of needles;

l_s is the shoot length (cm).

Both the planing procedure and the calculating procedures followed the instructions compiled by Aalto and Jalkanen [15]. The data was analysed by using the NTM program, designed specially for needle retention research at the Finnish Forest Research Institute.

Radial increment of the trees was measured on stem discs in the eastern and western directions with the precision of 0.01 mm by using a light microscope. In the analysis arithmetic means of two measures were used.

Yearly average levels of oil shale fly ash and SO_2 in the air for Kose were calculated by using the database of the air pollution sources and the computer program IMIT, both designed at the Institute of Ecology, Tallinn University of Educational Sciences [6, 16]. Because of the gaps in the database, the mean annual concentrations of air pollutants were calculated with the intervals of 5 years from 1960 to 1980, and then for 1990 and 1995.

Results

Height and Radial Growth Rates

The mean annual height increments of the pine trees varied between 31 and 64 cm at Kose, and between 9 and 37 cm at Lehtmetsa during the period 1964–1997 (Fig. 2*a*). The overall means of height increment of the 34-year-period were 26 and 47 cm yr^{-1} ($P < 0.001$) at Lehtmetsa and Kose, respectively. As the trees growing in Lehtmetsa stand were about 25 years older than those at Kose, the impact of ageing on the growth rates has to be considered. The comparison of even-aged trees revealed that at the young stage the trees at Kose grew remarkably faster than at Lehtmetsa: 65 versus 25 cm yr^{-1} at the age of 10 (Fig. 2*b*). The pines growing at Kose achieved the maximum growth rate earlier, but their height increments decreased sharper after the maximum. By the age of 30, the rates of height growth had been nearly equalised in both stands – 29 and 32 cm yr^{-1} ($P = 0.35$) at Lehtmetsa and Kose, respectively.

The annual radial increment of the trees measured at breast height varied from 1.06 to 3.71 mm at Kose, and from 0.52 to 1.40 mm at Lehtmetsa during the same period (Fig. 3*a*). The overall means of the period were 2.08 and 0.93 mm yr^{-1} ($P < 0.001$) at Kose and Lehtmetsa, respectively. In order to consider the effect of age on the growth rate, the age curves of the radial increment were compared (Fig. 3*b*). The radial growth rate of the trees, alike to height growth, was faster at Kose at the early stages of the development, while the increments became nearly equal by the age of 17 already – 1.61 mm yr^{-1} at Lehtmetsa and 1.62 mm yr^{-1} at Kose ($P = 0.9$). However, at the older age (over 23 years) pines growing at Kose demonstrated higher radial growth rates again as compared to the stand at Lehtmetsa. The maximum radial increments were observed at the age of three at Lehtmetsa, and at the age of four at Kose. After achieving the maximum value, the radial increments of the trees growing at Kose began sharply to decrease, whereas the decrease in trees at Lehtmetsa was slower.

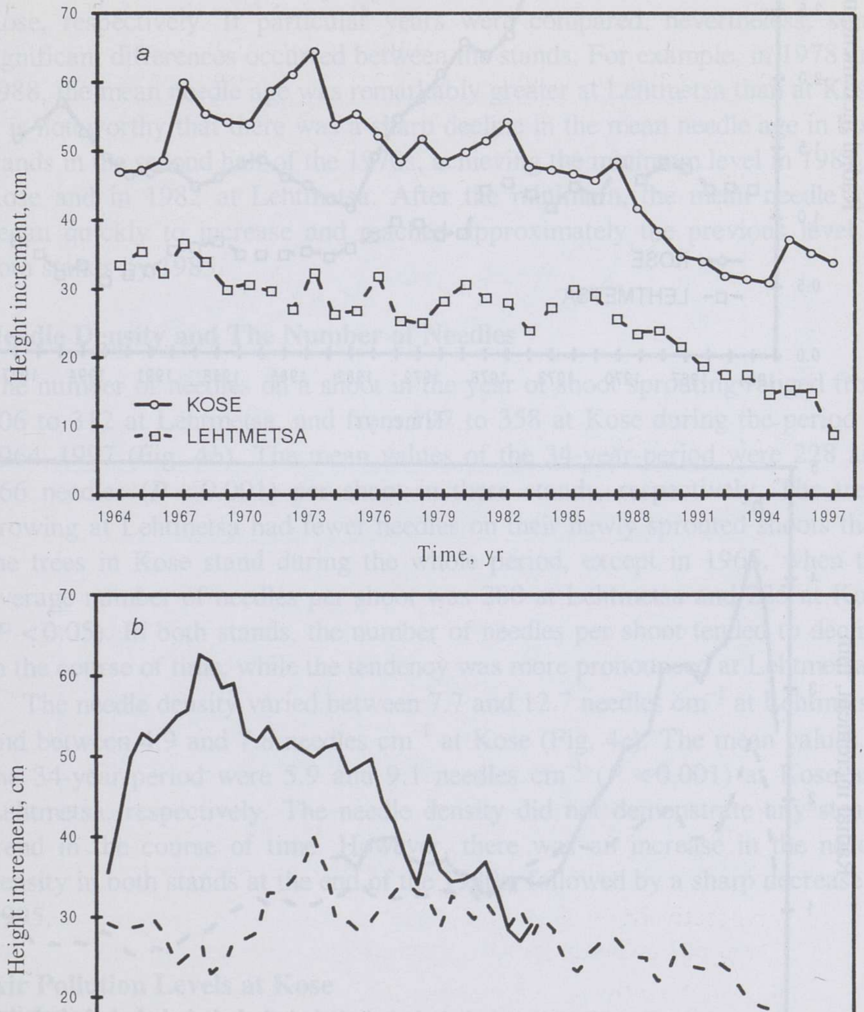

Fig. 2. Chronology of height increment (*a*), and changes in height increments with age (*b*)

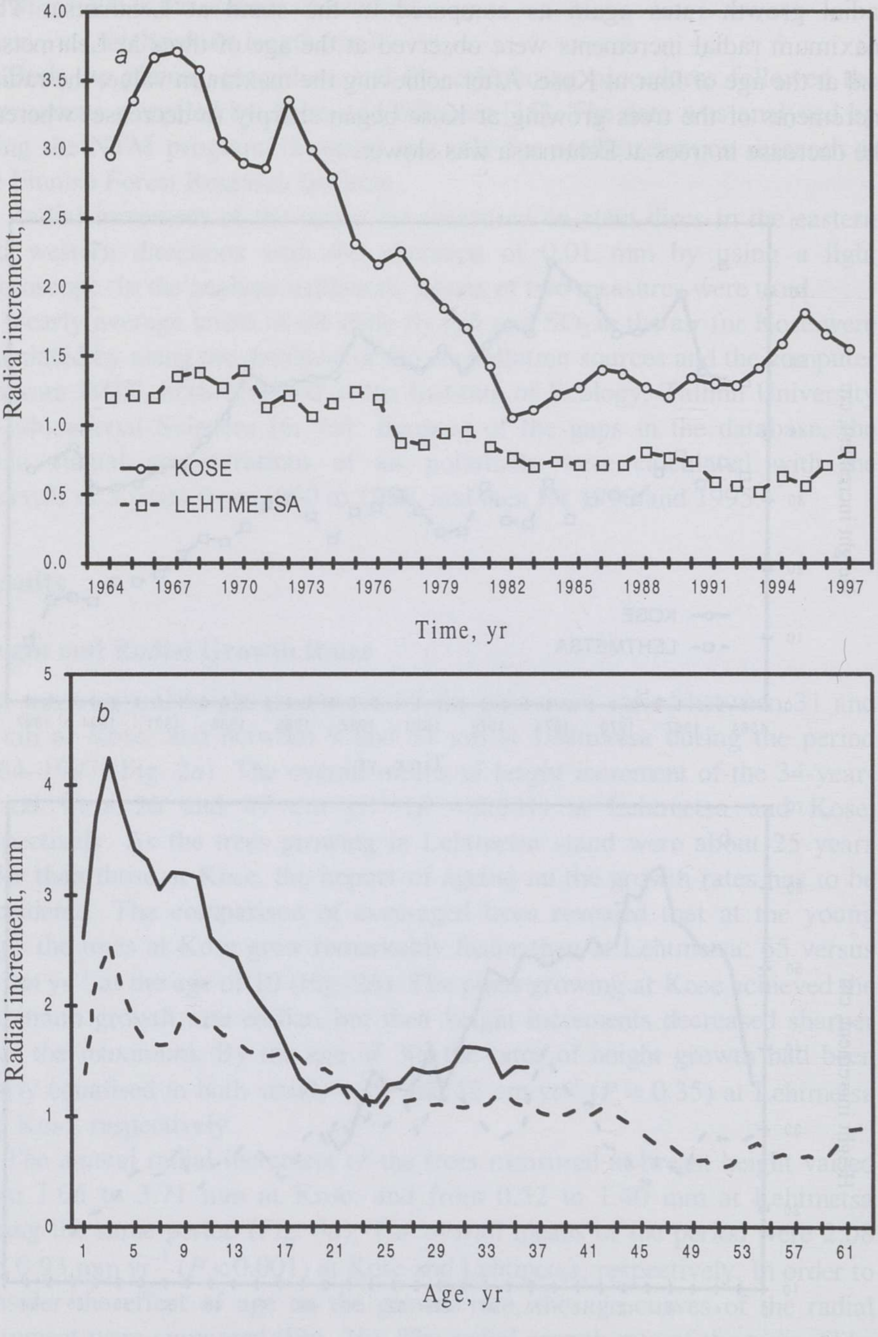

Fig. 3. Chronology of radial increment (*a*), and changes in radial increments with age (*b*)

Mean Needle Age

The mean needle age of pine trees ranged from 1.3 to 2.5 years at Lehtmetsa, and from 1.4 to 2.3 years at Kose during the period of 1964–1994 (Fig. 4*a*). There was not any steady trend in needle age chronology either in Lehtmetsa or Kose stands. The means of the 30-year-period did not differ significantly (P = 0.06) between the sample plots: 2.1 and 2.0 years for Lehtmetsa and Kose, respectively. If particular years were compared, nevertheless, some significant differences occurred between the stands. For example, in 1978 and 1988, the mean needle age was remarkably greater at Lehtmetsa than at Kose. It is noteworthy that there was a sharp decline in the mean needle age in both stands in the second half of the 1970s, achieving the minimum level in 1981 at Kose and in 1982 at Lehtmetsa. After the minimum, the mean needle age began quickly to increase and reached approximately the previous level in both stands by 1985.

Needle Density and The Number of Needles

The number of needles on a shoot in the year of shoot sprouting ranged from 106 to 312 at Lehtmetsa, and from 197 to 358 at Kose during the period of 1964–1997 (Fig. 4*b*). The mean values of the 34-year-period were 228 and 266 needles (P <0.001) per shoot in these stands, respectively. The trees growing at Lehtmetsa had fewer needles on their newly sprouted shoots than the trees in Kose stand during the whole period, except in 1965, when the average number of needles per shoot was 280 at Lehtmetsa and 225 at Kose (P <0.05). In both stands, the number of needles per shoot tended to decline in the course of time, while the tendency was more pronounced at Lehtmetsa.

The needle density varied between 7.7 and 12.7 needles cm^{-1} at Lehtmetsa, and between 4.9 and 7.8 needles cm^{-1} at Kose (Fig. 4*c*). The mean values of the 34-year-period were 5.9 and 9.1 needles cm^{-1} (P <0,001) at Kose and Lehtmetsa, respectively. The needle density did not demonstrate any steady trend in the course of time. However, there was an increase in the needle density in both stands at the end of the 1980s, followed by a sharp decrease in 1995.

Air Pollution Levels at Kose

The annual mean concentrations of oil shale fly ash in the air were very high from 1960 to 1975, ranging up to 95 μg m^{-3} (Fig. 5). After 1977, when electrostatic filters were installed in Ahtme Power Plant, the emission of fly ash dropped abruptly to 6.11 μg m^{-3} by 1980. Afterwards the concentration of fly ash declined even more due to economical depression, averaging 5.25 and 2.25 μg m^{-3} in 1990 and 1995, respectively.

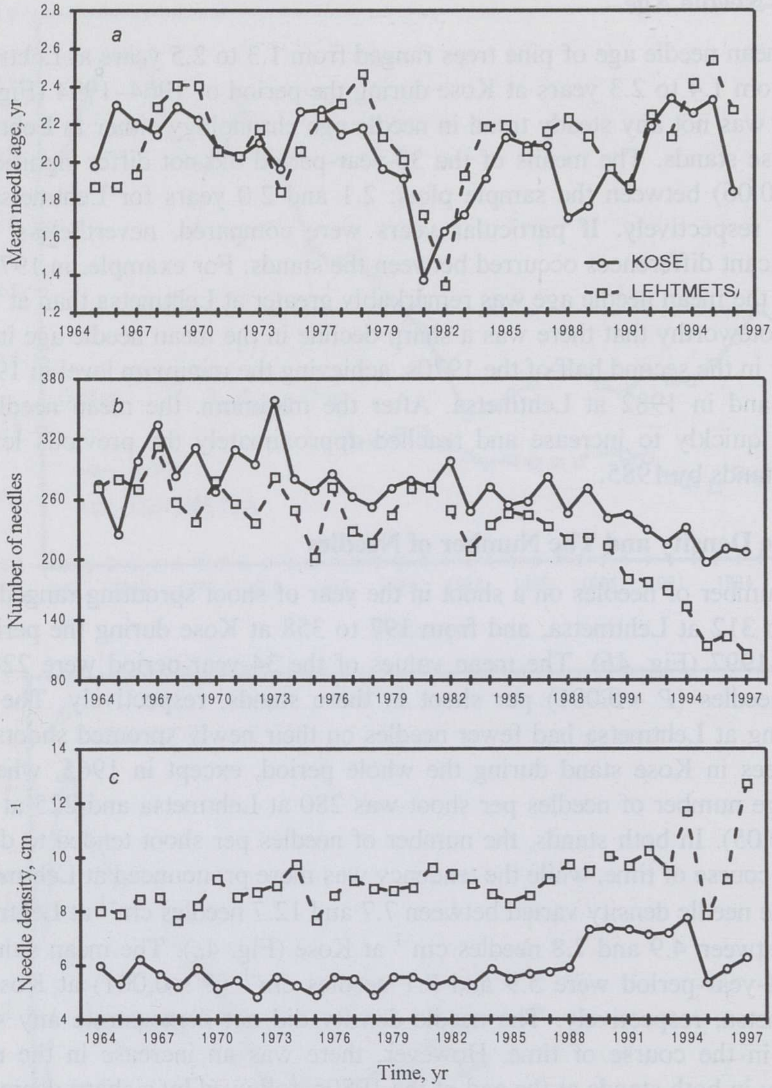

Fig. 4. Chronologies of mean needle age (*a*), number of needles on newly sprouted shoots (*b*), and needle density (*c*)

The short-term maximum concentrations of fly ash ranged from 2278 to 3294 μg m^{-3} in 1960–1975, and from 54–202 μg m^{-3} in 1980–1995. On the contrary, the annual mean concentration of SO_2 in the air was more stable during the period under discussion: it varied between 2.47 and 10.3 μg m^{-3}. The short-term maximum concentration of SO_2 ranged from 76 to 314 μg m^{-3}.

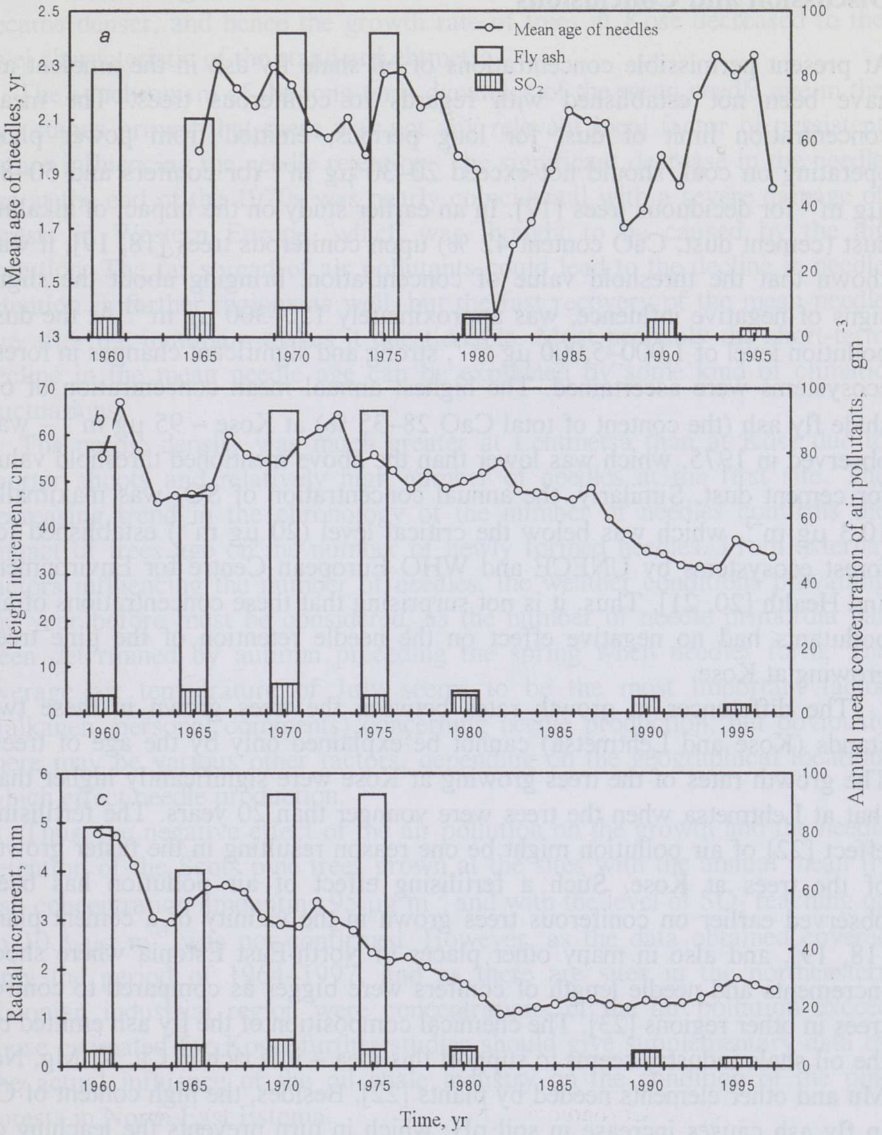

Fig. 5. Changes in annual mean concentrations of oil shale fly ash and SO_2, and chronologies of mean needle age (*a*), height increment (*b*) and radial increment (*c*)

Because of the gaps in the data on pollutant concentrations, it was not possible to find a strict correlation among the pollution levels, needle retention and growth of trees. However, the variation in growth and needle retention of the trees growing at Kose in the course of time can hardly be explained by the changes in the air pollution levels (Fig. 5).

Discussion and Conclusions

At present permissible concentrations of oil shale fly ash in the ambient air have been not established with regards to coniferous trees. The mean concentration limit of dust for long periods, emitted from power plant operating on coal, should not exceed 20–30 $\mu g\ m^{-3}$ for conifers and 50–80 $\mu g\ m^{-3}$ for deciduous trees [17]. In an earlier study on the impact of alkaline dust (cement dust, CaO content 42 %) upon coniferous trees [18, 19], it was shown that the threshold value of concentration, bringing about the slight signs of negative influence, was approximately 150–300 $\mu g\ m^{-3}$. At the dust pollution level of 1,000–5,000 $\mu g\ m^{-3}$, strong and significant changes in forest ecosystems were ascertained. The highest annual mean concentration of oil shale fly ash (the content of total CaO 28–35 %) at Kose – 95 $\mu g\ m^{-3}$ – was observed in 1975, which was lower than the above mentioned threshold value for cement dust. Similarly, the annual concentration of SO_2 was maximally 10.3 $\mu g\ m^{-3}$, which was below the critical level (20 $\mu g\ m^{-3}$) established for forest ecosystems by UNECE and WHO European Centre for Environment and Health [20, 21]. Thus, it is not surprising that these concentrations of air pollutants had no negative effect on the needle retention of the pine trees growing at Kose.

The differences in growth rates between the trees grown in these two stands (Kose and Lehtmetsa) cannot be explained only by the age of trees. The growth rates of the trees growing at Kose were significantly higher than that at Lehtmetsa when the trees were younger than 20 years. The fertilising effect [22] of air pollution might be one reason resulting in the faster growth of the trees at Kose. Such a fertilising effect of air pollution has been observed earlier on coniferous trees grown in the vicinity of a cement plant [18, 19], and also in many other places in North-East Estonia where shoot increments and needle length of conifers were bigger as compared to control trees in other regions [23]. The chemical composition of the fly ash emitted by the oil shale industry seems to support this idea – it is rich in Ca, K, Mg, Na, Mn and other elements needed by plants [22]. Besides, the high content of Ca in fly ash causes increase in soil pH, which in turn prevents the leaching of nitrogen and other nutrients from the soil. Also the concentrations of NO_x in the air of North-East Estonia have been reported to be above the level, which may have a remarkable influence on plant communities [24].

Nevertheless, there is one more explanation to the faster growth of the trees in Kose stand. This may arise from possible differences in light conditions due to the diverse origin of the stands: Kose stand has been seeded by man, and the stand at Lehtmetsa is most probably of natural origin. Although the last fact is not exactly known, it can be supposed from the higher variability in the age of the trees growing at Lehtmetsa. Probably better light conditions in artificial plantations as compared to natural stands must favour the growth of trees at Kose. As the trees grew up, the canopy became denser, and hence the growth rate of trees at Kose decreased to the level characteristic of the stand at Lehtmetsa.

The synchronism of the long-term dynamics of the mean needle age in the two stands proved that there was not any relevant local factor of persistent nature influencing the needle retention. The significant decrease in the needle age at the end of the 1970s was nearly coincidental with a severe damage of forests in Western Europe, which was thought to be caused by the air pollution. The far spread of air pollutants could lead to the decline in needle retention in farther regions as well, but the fast recovery of the mean needle age after the minimum makes it questionable. Most probably the short-term decline in the mean needle age can be explained by some kind of climatic fluctuations.

The needle density was much greater at Lehtmetsa than at Kose due to shorter shoots and relatively high number of needles at the first site. The decreasing trend in the chronology of the number of needles confirms the impact of trees age on the number of newly formed needles. From external factors influencing the number of needles, the weather conditions prevailing the year before must be considered, as the number of needle primordia has been determined by autumn preceding the spring when needles form. The average air temperature of July seems to be the most important factor (Jalkanen, personal comments) concerning needle production, but obviously there may be various other factors, depending on the geographical location, which effect needle production.

Thus, the negative effect of the air pollution on the growth and the needle retention of the Scots pine trees grown at the sites with the annual mean fly ash concentration amounting 95 $\mu g\ m^{-3}$ and with the level of SO_2 reaching up to 10.3 $\mu g\ m^{-3}$ was not confirmed. However, as the data obtained covered only the period of 1964–1997, and as there are sites in the northeastern Estonian industrial region were concentrations of the air pollution exceed those estimated for Kose, further studies should give supplementary data on the actual influence of the oil shale industry on the condition of the pine forests in North-East Estonia.

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