Needle Chronologies on *Pinus sylvestris* in Northern Estonia and Southern Finland

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A needle trace method was used to reveal the chronology of needle retention on Scots pine (*Pinus sylvestris* L.) in southern Finland (two stands) and northern Estonia (two stands). The average annual summer needle retention along the main stem varied from 2.2 to 3.1 in Estonian stands and between 3.4 and 4.2 in Finnish stands during the period 1966–1990. The 23-year-mean needle age was 3.0 and 2.1 years in Finland and Estonia, respectively. In all stands, the mean needle age decreased sharply in 1980s.

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1 Introduction

In the early 1980s, a severe and rapidly increasing decline of coniferous forests attracted public attention in Central Europe. To obtain a clear picture of the extent and severity of damage, forest health surveys were carried out in many countries. According to the percentage of needle loss and the discoloration of the foliage, the damage category of forests was assessed. However, the methods of damage assessment had been heavily criticised. It had been suggested that knowledge about the natural variation in needle loss were not sufficient to draw border between healthy and damaged trees (Blank 1985). The second problem was the missing data about long-term variation in needle retention. So it was impossible to compare the extent of defoliation with the past thinning of crowns (Blank et al. 1988). Thirdly, the available methods for forest health assessments were highly subjective. There were reports that if the same methods were used by the different researchers on the same trees, the results were often very different (Innes 1993).

In the beginning of the 1990s, a new method for a retrospective assessment of needle reten-

tion on pine trees was developed (Kurkela and Jalkanen 1990). The needle trace method (NTM) allows quantifying the long-term variation in needle retention on a single tree. It has been used for revealing a past needle-cast epidemic (Jalkanen et al. 1994a) and a long-term negative impact of air pollution on needle retention (Jalkanen 1996). Additionally, the NTM has produced the chronology of needle retention in two pine stands in England (Jalkanen et al. 1994b) and in numerous stands in northern and southern Finland (Jalkanen et al. 1995).

The aim of the present study was to obtain the long-term data about needle retention in Scots pine (*Pinus sylvestris* L.) in northern Estonia, and to compare those data with the long-term needle retention of pine trees grown in southern Finland.

2 Material and Methods

Two Scots pine stands were chosen in southern Finland in 1990, and in northern Estonia in 1998. In Finland the stands were located in Tuusula and in Ruotsinpyhtää, in Estonia the locations were in Kose and in Lehtmetsa. In each stand ten pine trees were felled according to guidelines provided by Aalto and Jalkanen (1998). The trees

belonged to the main storey not dominated by older trees. They had straight, unbroken stems, and their crowns were regular-shaped (Table 1).

Stands in Ruotsinpyhtää and in Tuusula, in southern Finland, and in Lehtmetsa, in northern Estonia, were naturally seeded; Kose had been seeded by man. The stands in southern Finland had been regularly thinned with the interval of 10 years while Estonian stands had grown without interference during the studied period. The trees from the stands in southern Finland were the same as were previously investigated by Jalkanen et al. (1995).

Prior to the felling of the trees, the compass direction was marked on the east side of each tree. After felling, the compass direction was extended along the whole length of each stem. On every tree, the number of needle sets was assessed in 25 per cent classes for the main stem and also for 3 to 5 branches from the 10th whorl from the top of the tree. Discs from each tree were obtained at breast height for subsequent measurements of radial increment. The parts of the stems above breast height were sectioned into bolts, corresponding to annual shoots, by omitting the branch whorls as instructed by Aalto and Jalkanen (1998). However, the youngest (the most recent 5–9 years) sections of the stems were kept intact while they were transported to laboratory.

Table 1. Basic information of the sampling sites.

Southern Finland

Location	N	E	Altitude, m a.s.l.	Thermal sum[*], deg. days	Forest site[**]	Age, yr	Height, m	d.b.h., cm	Trees no.
Ruotsinpyhtää	60°32'	26°27'	30	1320	sub-dry	45	15.1	16.3	10
Tuusula	60°21'	24°57'	60	1290	sub-dry	53	16.3	16.0	10
Mean			45	1305		49	15.7	16.15	10

Northern Estonia

Location	N	E	Altitude, m a.s.l.	Thermal sum, deg. days	Forest site	Age, yr	Height, m	d.b.h., cm	Trees no.
Lehtmetsa	59°12'	25°35'	60	1650	sub-dry	65	18.7	14.9	10
Kose	59°19'	27°32'	45	1700	sub-dry	40	17.7	14.9	10
Mean			52.5	1675		52.5	18.2	14.9	10

[*] Treshold value +5 °C.
[**] *Vaccinum vitis-idaea* was the dominant species in ground vegetation in all stands.

In the laboratory, each annual bolt was planed along the marked east side, tree ring by tree ring, towards the pith of the shoot, and the number of needle traces in the planed surface of the 5–6 innermost tree ring was recorded. Thus, it was assumed that the age of the oldest needles would be no more than six growing seasons. The recordings of the needle trace data were used for calculating annual needle retention, annual needle loss and mean needle age. The needle retention (NR_t) value was calculated as the sum of percentages of needles on each shoot in year t:

$$NR_t = \frac{\sum \left[x_t, (x-1)_t ... (x-n)_t \right]}{100}$$

where x_t is the percentage of needles on shoot x present in year t, $(x-1)_t$ is the percentage of needles in year t on the shoot initiated the year before shoot x, and so on. Consequently, annual needle loss (ANL_t) was calculated by:

$$ANL_t = (NR_t - NR_{t+1}) + 1$$

where the term 1 represents the new flush of needles in year $(t+1)$. The formula for computing mean age of needles (NA) born in a certain year was following:

$$NA = \sum_{r=1}^{n} \left[(x_r - x_{r+1}) \left(r - 1 + \frac{m}{12} \right) \right]$$

where x_r is the relative number of needles x in annual ring r in the bolt, m is the number of months between the birth of new needles and the yellowing of oldest needles (this was taken as three months in present study). Both the planing procedures and calculating procedures followed the instructions compiled by Aalto and Jalkanen (1998). Data were analysed by the NTM program, which was specifically constructed for the needle retention research at the FFRI.

The statistical differences between the Estonian and Finnish study stands were investigated by means of paired *t*-test at significance level $p = 0.05$. The trendlines describing long-term changes in needle retention with time were estimated by non-linear transformation, multiple regression analysis (Statistica 1998).

3 Results

3.1 Needle Retention

The period during which the data from both countries were comparable was 25 years long, from 1966 to 1990. During that period, annual average needle retention values for summer time varied from just above 3.1 to 2.2 needle sets in Estonia, and between 3.1 and 4.2 in Finland (Fig. 1a). The 25-year-mean of 20 trees in Estonia (mean ± SD = 2.8 ± 0.2) was significantly lower ($p < 0.001$) than in Finland (3.7 ± 0.2). The long-term difference in needle retention within study areas was not significant for both Finland and Estonia (0.1 needle sets between Tuusula and Ruotsinpyhtää, and 0.0 between Lehtmetsa and Kose). As the trees from Finnish study stands had a typical long-term pattern best described by a convex trendline ($R^2 = 0.53$, $p < 0.001$), the trees from Estonian stands were with less obvious concave pattern ($R^2 = 0.09$, $p < 0.05$) (Fig. 2). However, the short-term pattern was quite similar: the peaks up and down happened parallelly in needle retention chronology (Fig. 1a).

3.2 Needle Age

Average standwise needle age varied annually between 2.6 and 3.4 years in Finland, and 1.5 and 2.3 years in Estonia from 1964 to 1986 (Fig. 1b). The 23-year-mean needle age was significantly higher ($p < 0.001$) in Finland (3.0 ± 0.2) than in Estonia (2.1 ± 0.2). The average minimum occurred in Kose in 1980 (1.4 ± 0.3), and in Lehtmetsa in 1981 (1.3 ± 0.5); these values were significantly lower ($p < 0.001$) than the long-term average of mean needle age. In Finnish experimental stands the minima were achieved in 1980 (2.7 ± 0.4 and 2.7 ± 0.6 in Tuusula and in Ruotsinpyhtää, respectively), which differed significantly ($p < 0.05$) from long-term value of mean needle age.

3.3 Needle Shed

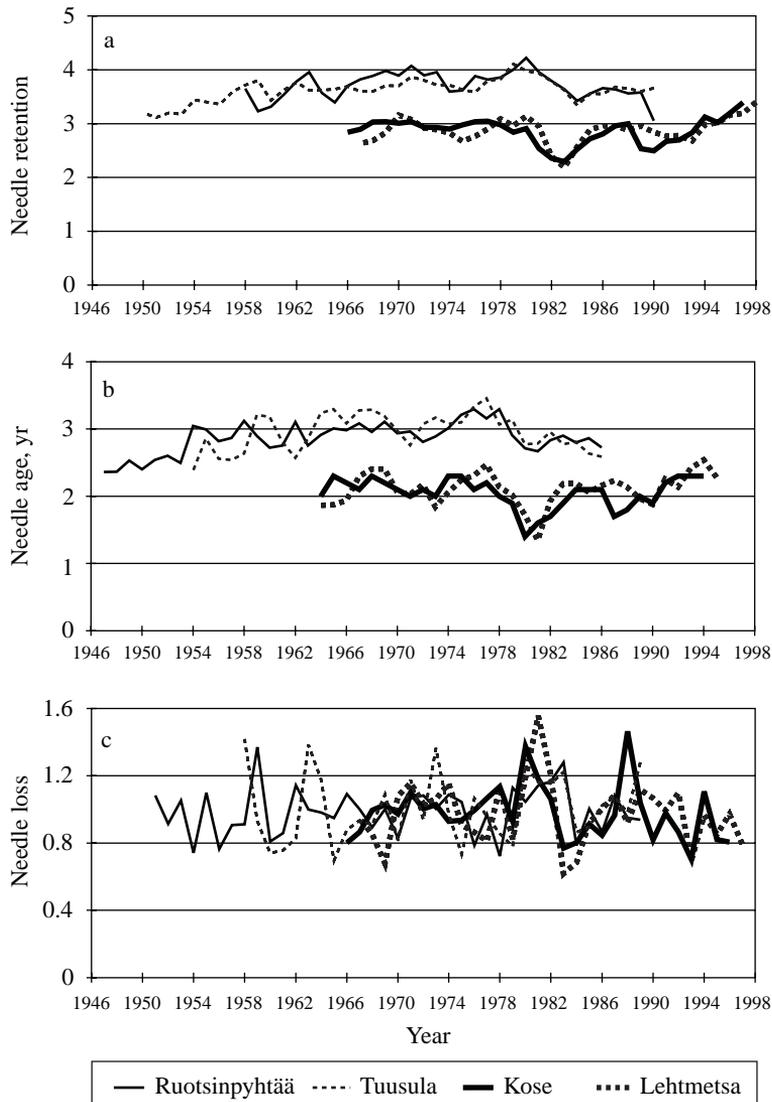The average (within country) amount of annual needle loss varied between 0.6 and 1.5 needle

Fig. 1. Needle chronologies on *Pinus sylvestris* in Kose and Lehtmetsa in northern Estonia, and in Tuusula and Ruotsinpyhtää in southern Finland, a) needle retention; b) needle age; c) needle loss.

sets in Estonia, and 0.7 and 1.4 in Finland (Fig. 1c). The pattern of needle loss was quite similar within country. The 23-years (from 1967 to 1989) means of needle loss did not differ significantly between countries (p = 0.8). There had occurred a strong shedding in Estonia in 1980–1982 (both stands) when up to 1.5 needle sets was lost. The same happened in Finland in 1980–1983

(Ruotsinpyhtää, 1.3 needle sets) and in 1979–1983 (Tuusula, 1.2 needle sets). Needles were shed younger in Estonia than in Finland (Fig. 3). From 7.3 to 8.4 % of all needles lived only one growing season in Estonia, whereas there were only 0.3 to 1.1 % of needles in this class in Finland. Correspondingly 14.9–15.3 % of the needles lived five years, some (0.5–1.0 %) even
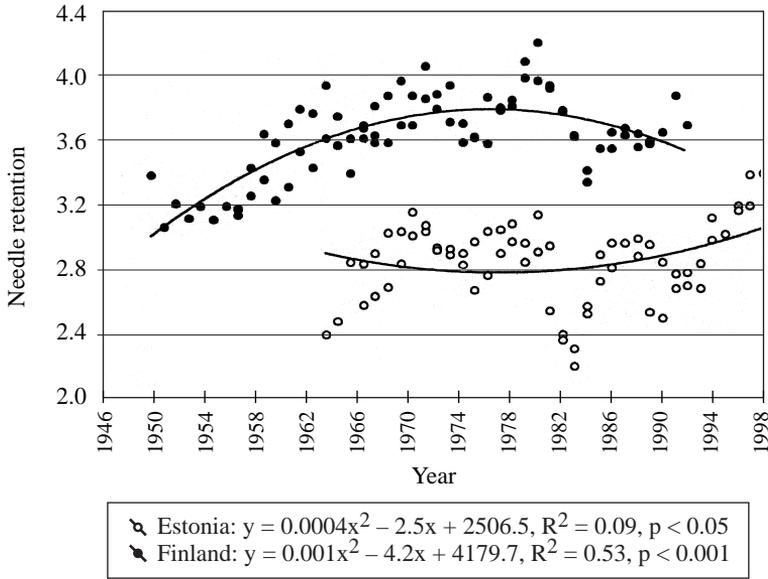
Estonia: $y = 0.0004x^2 - 2.5x + 2506.5$, $R^2 = 0.09$, $p < 0.05$
Finland: $y = 0.001x^2 - 4.2x + 4179.7$, $R^2 = 0.53$, $p < 0.001$

Fig. 2. Long-term changes in needle retention with time.
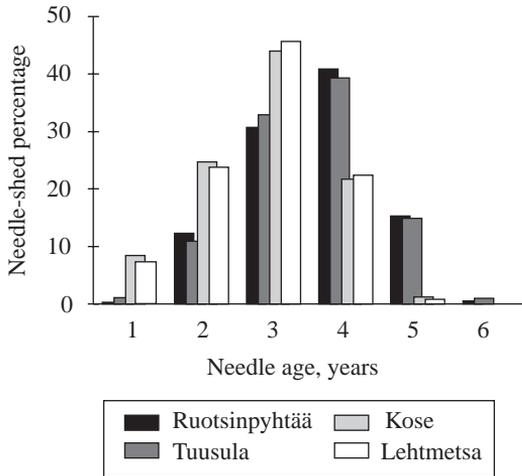

Fig. 3. Distribution of needle-shed percentage according to needle age.

six years in Finland, but only 0.8–1.2 % of the needles lived five years in Estonia (Fig. 3). Medium age for needle shedding was three and four years in Estonia and in Finland, respectively.

4 Discussion

Expectedly, the number of needle sets was greater in southern Finland than in northern Estonia. This is in good agreement with the latitudinal variation in the number of needle sets as shown by Pravdin (1964) in Russia, and by Jalkanen et al. (1995) in Finland. The correlation between the number of needle sets and latitude is related to the latitudinal variation in thermal sums (Jalkanen et al. 1995). The impact of thermal sum on the number of needle sets indicates an important role of climate (summer temperatures) in determining the level of needle longevity. Variation in the mean needle retention among the studied stands was the same in both countries.

Variation in needle retention with time showed two types of temporal variation. The first type of variation was connected to entire period under examination, from about breast height age to the present. In Finnish experimental stands the needle retention increased at first, then it reached its maximum and in the last stage it began to decrease. As have been shown in earlier reports, such pattern of needle retention was found also in southern England (Jalkanen et al. 1994b) and

in northern Finland (Jalkanen et al. 1995). However, in Estonian study stands the trees had opposite pattern – the needle retention decreased at first, then it began to increase. The factors having influence on long-term pattern of needle retention are unknown yet, but the difference between Estonian and Finnish stands allows to suppose that there is not a general way how the needle retention varies over the lifespan of Scots pine. The explanation could rather be sought from the differences in silvicultural procedures. As the stands in Finland were regularly thinned with the approximate interval of 10 years, the stands in Estonia had grown undisturbedly from the very beginning until 1996 in Lehtmetsa and 1997 in Kose. Thus in Finland the trees grew under better light conditions than in Estonia, which might induce the needle retention to increase until the canopy closure of the stands.

Interestingly, the number of needle sets as well as the mean needle age began to increase in both stands in Estonia in 1990s. Due to the absent of data about southern Finland, it was not possible to compare trends of 1990s between Estonia and Finland. Thus it is unclear whether this is a regional or merely a local phenomenon.

The second type of variation included short-term changes in the level of needle retention, which was notable in all experimental stands. To find out the reason for this variation, it is necessary to examine the factors influencing the mean age of needles flushed in a certain year. The mean age of needles varied up and down with 2–7 years intervals, which caused corresponding variation in needle retention and in needle loss (Fig. 1). This short-term variation can not be caused by silvicultural practises because the intervals between repeated peaks are too short, and in Estonia the stands had not been thinned before the mid 1990s. The simultaneity of the pointer years in needle age chronology suggests that the factors causing short-term variation are regional, rather than local. One drastic decrease in needle age occurred at the beginning of 1980s. In all study stands the needles born then lived significantly less as compared with the long-term average life duration of needles (Fig. 1b).

The climate could be one of the factors that have an important role in determining the short-term variation in needle longevity. However, the sharp decrease in mean needle age in the first half of 1980s can hardly be explained only by weather conditions. The decline of mean needle age was prevailing 2–3 successive years but there was not such a steady trend in weather conditions either in Estonia or in Finland at that time. Although, if considering the circumstances for carbon assimilation, the totally different summers – drought in 1976 and extreme rainfall in 1978 and 1979 (and therefore a low level of irradiance) – might cause the rate of net photosynthesis to be dropped. This in its turn might have influenced the state and hardiness of the needles born in those years and soon after. Nevertheless, the decrease of mean needle age in early 1980s observed in this study was nearly simultaneous with the widespread damage of coniferous forests in western Europe, so it is likely that in both cases there was the same reason. In western Europe the forest decline was thought to be a direct consequent of air pollution. The far spreading of air pollutants in combination with climate might also give rise to the decrease in needle longevity in areas under discussion.

Acknowledgements

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