Proc. Estonian Acad. Sci. Ecol., 1993, 3, 1, 8—16
https://doi.org/10.3176/ecol.1993.1.02

*Priit KASK** and *Jane FREY**

VITALITY OF NORWAY SPRUCE AND SCOTCH PINE ASSESSED BY THE CROWN CLASS AND RADIAL INCREMENT

Abstract. Crown damage and radial growth assessment is used for surveying forest vitality in the total of about 200 Scotch pines and Norway spruces on 10 permanent plots. The crown damage was estimated using a five-class system. Regression analysis was applied to determine relationships between radial growth and crown damage variables. Social conditions of trees were expressed as the Kraft growth class; the competition index was included in the analysis.

No effect of social conditions on radial growth was revealed. A statistically significant correlation between the crown class and radial growth was found for growth classes I and II; the correlation for pine was stronger than for spruce. In general radial growth has had an increasing trend in recent years with decreases occurring when needle loss exceeded 60%. The correlation between radial increment and needle loss is different for Scotch pine and Norway spruce due to their different needle age and ability to compensate for needle loss.

Because of several methodological difficulties, the use of such surveys for the prognostication of forest growth is risky.

Key words: Norway spruce, Scotch pine, crown damage, radial growth, monitoring.

Introduction

The assessment of defoliation in individual tree crowns is used as a method for surveying forest vitality in the monitoring programmes of many countries (Salemaa and Jukola-Sulonen, 1990). However, visual estimation of defoliation involves a number of methodological problems and therefore significant variation may occur in the results of different observers. Hence, comparison of visually estimated damage symptoms with metric variables is of great value. Radial increment is a very important metric variable since it is directly related to biomass production. Reflecting the state of the site, social conditions of stands, and former radial increment, the radial increment of a tree is not only one of the most important diagnostic variables but also a measure of the importance of other symptoms. A symptom not correlating with increment is not likely to be useful in estimating the severity of injury. On the other hand, interpretation of radial growth data poses a number of methodological problems caused by numerous different factors influencing the width of the annual ring and, consequently, annual increment. The most important factor is weather conditions, while such factors as age, thinning of a stand, and competition of neighbouring trees can either strengthen or compensate for the influence of weather conditions. This makes it extremely difficult to determine the contribution of individual factors to the variation of the width of annual rings. Consequently, not even continuous reduction of the ring width through several years can prove the effect of air pollution. Extrapolation from a few individual trees to the whole stand is and has always been a serious methodological problem (Steinlin, 1985).

* Ecology Station, Tartu University, Ülikooli St. 18, EE-2400 Tartu, Estonia.

Therefore, researchers studying the relationship of the condition of the crown and radial growth have obtained contradictory results. Waring et al. (1980, 1981), Waring (1987), Schütt and Cowling (1985), Schulze (1989), and Salemaa and Jukola-Sulonen (1990) found that any stress, if sustained, reduced the canopy, photosynthetic activity, and storage reserves throughout the tree and also wood production due to foliage decrease. Plochmann (1984), Kramer (1986), Schweingruber (1985), and Schmid-Haas (1989) did not find any correlation between canopy decline and radial increment. Their explanation is the following: (1) there is a time lag of about 3—5 (10) years between the regeneration of the crown and its reflection in the tree ring pattern; (2) stem and crown dimensions, growth space, and the competition of neighbouring trees can substantially outweigh the influence of crown damage on radial increment; (3) the falling of older spruce needles can improve the conditions for the remaining younger ones and increase their photosynthetic activity and production capacity.

Material and Methods

The total of about 200 increment cores were bored on ten permanent forest plots in September-October 1991. The crown classes were estimated for each tree by J. Frey. All trees were grouped into three Kraft growth classes: I — superdominants (42.5%), II — codominants (35.6%), and III — dominants (21.9%).

Usually defoliation is assessed as the degree of crown thinning in a five-class system, taking 0—10% defoliation as class 0; 11—25% as class 1; 26—60% as class 2; 60% and more as class 3; and dead trees as class 4 (Draft Manual..., 1986). We determined the combined damage class on the basis of the defoliation rate, taking into consideration also discolouration of needles and other visible damage symptoms (sap flow, mechanical injuries). Thus, these data can be used as information on the health of a sample tree in the five crown class system:

Class 0 — not damaged;
Class 1 — slightly damaged;
Class 2 — moderately damaged;
Class 3 — severely damaged;
Class 4 — dead.

The annual growth rates in each Kraft class in 1988, 1989, 1990, and 1991 were subjected to regression analysis against crown class variables with the regression equation, correlation coefficient, and significance level calculated. The mean growth rates for the years 1980—1991 were calculated and, dividing the annual growth (j_{zi}) by the mean of 12 years ($j_{z1980-1991}$), the radial growth index (I_i) was found for 1988, 1989, 1990, and 1991:

$$I_i = j_{zi}/j_{z\,1980-1991}.$$

Regression analysis was used for the estimation of the relationship of the crown class and the growth indices. Spruce and pine were analysed separately.

The distance between the nearest dominant trees (max. five) and the test tree within a radius of 6 m was measured. The competition effect was studied using the following competition index:

$$I = 1000[(1/D)/n],$$

where D is the distance and n is the number of neighbouring trees.

The radial growth value for 1983—1991 and the relative radial growth (growth value divided by the radius of the tree) were subjected to regression analysis against the distance index.

Results and Discussion

No correlation was observed between the radial growth for 1983—1991 and the distance index. So the neighbour effect on radial growth was absent in our case. We did not find any correlation between the Kraft growth class of a tree and its radial growth rate, either. It can be concluded that the main social conditions of trees had no effect on their radial increment. This is plausible considering that old stands were monitored, where competition for better conditions has already been completed.

Statistically significant correlations between the crown class and the annual radial growth rate were revealed in superdominant (growth class I) and codominant (growth class II) trees. The radial growth rate was determined up to 20% by the crown condition. In pine stands the radial growth index was determined up to 10% by the crown class. No correlation was revealed for spruce stands. The strongest correlations were found for 1990, which is the year with the most favourable climatic conditions throughout the whole period studied (Table).

Correlation between radial growth (*jz*) and crown class (*cc*)

	cc 1988	*cc* 1989	*cc* 1990	*cc* 1991
A. Kraft class I				
jz 1988	$r=-0.27$ $P<0.05$	—	$r=-0.41$ $P<0.001$	—
jz 1989	—	$r=-0.23$ $P<0.05$	$r=-0.37$ $P<0.001$	—
jz 1990	—	—	$r=-0.30$ $P<0.01$	—
jz 1991	—	—	$r=-0.26$ $P<0.05$	—
B. Kraft class II				
jz 1988	$r=-0.25$ $P<0.05$	—	$r=-0.18$ $P<0.001$	—
jz 1989	—	$r=-0.40$ $P<0.01$	—	—
jz 1990	—	—	—	$r=-0.39$ $P<0.01$
jz 1991	—	—	—	$r=-0.44$ $P<0.001$

No correlation between the crown class and the annual radial growth occurred in the case of dominant trees (growth class III). Trees of this class are subjected to more influences than those in classes I and II and therefore the effect of their crown damage is very weak. According to Bauch et al. (1988) trees in classes I and II are more strongly influenced by climate and other environmental conditions than those of class III. It can be concluded that the trees of these two classes are more exposed to airborne pollutants, hence their defoliation is mainly related to the effect of air pollution.

The radial increment was generally related to the crown class of the same year. In a few cases the radial increment had a correlation with the crown class of the next year, but not vice versa (i.e. the crown class was not correlated with the next year's radial increment). This confirms the supposition of Kramer (1986), Schweingruber (1985), and Plochmann (1984) that damage in the year of the survey is related to the increment of the previous year, so a time lag is possible (one year in our case).

The connection between the inhibition of increment and the extent of needle loss is different for Norway spruce and Scotch pine. The most common form of defoliation in Norway spruce is needle loss throughout the crown from the inside towards the outside, i.e. the trees drop older needles prematurely. In normal ecological conditions the needle age in spruce is usually up to ten years; the needles of the last three years form a photosynthetically important part, their mass being about 50% of the total needle mass. In Scotch pine, however, the needle age is up to four years (usually three years), the main needle mass belonging to two first sets; thus, the loss of needles in one annual set may cause decisive changes in growth trends. On the other hand, pine has no ability to form additional or adventive shoots like spruce, i.e. the ability to compensate for needle loss to a considerable extent. This accounts for the better correlation between radial increment and the extent of needle loss for pine as compared to spruce.

The radial growth index showed in general an increasing trend in 1988—1991 (Fig. 1). The mean value of the radial growth index was above 1 for this period except in the case of stands on Vigala and Putkaste plots. This increase may be connected with very favourable weather conditions and/or additional nutrient supply due to increasing air pollution, especially nitrogen saturation as also suggested by Aber et al. (1989). At the same time the crown state became generally worse (Fig. 3). Diminished radial growth has been found to accompany defoliation and to occur in conifers when needle loss exceeds 60% (classified as severe damage, crown damage class III) (Fig. 2). This finding is also supported by Bauch et al. (1988).

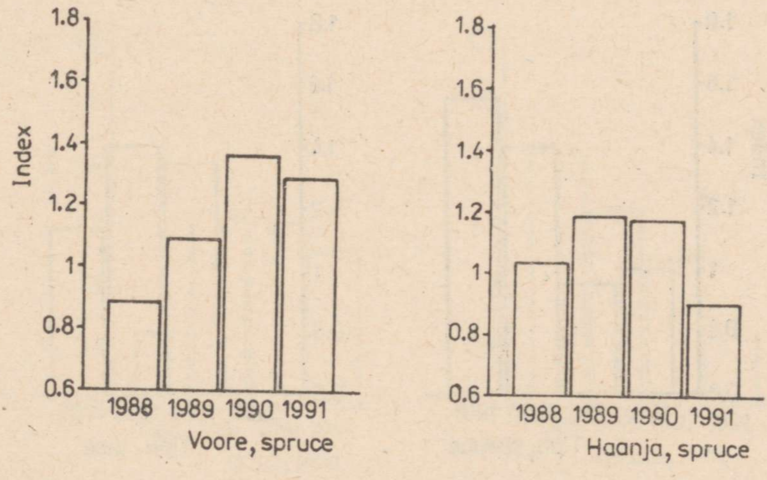

Fig. 1. Radial growth indices for 1988—1991.

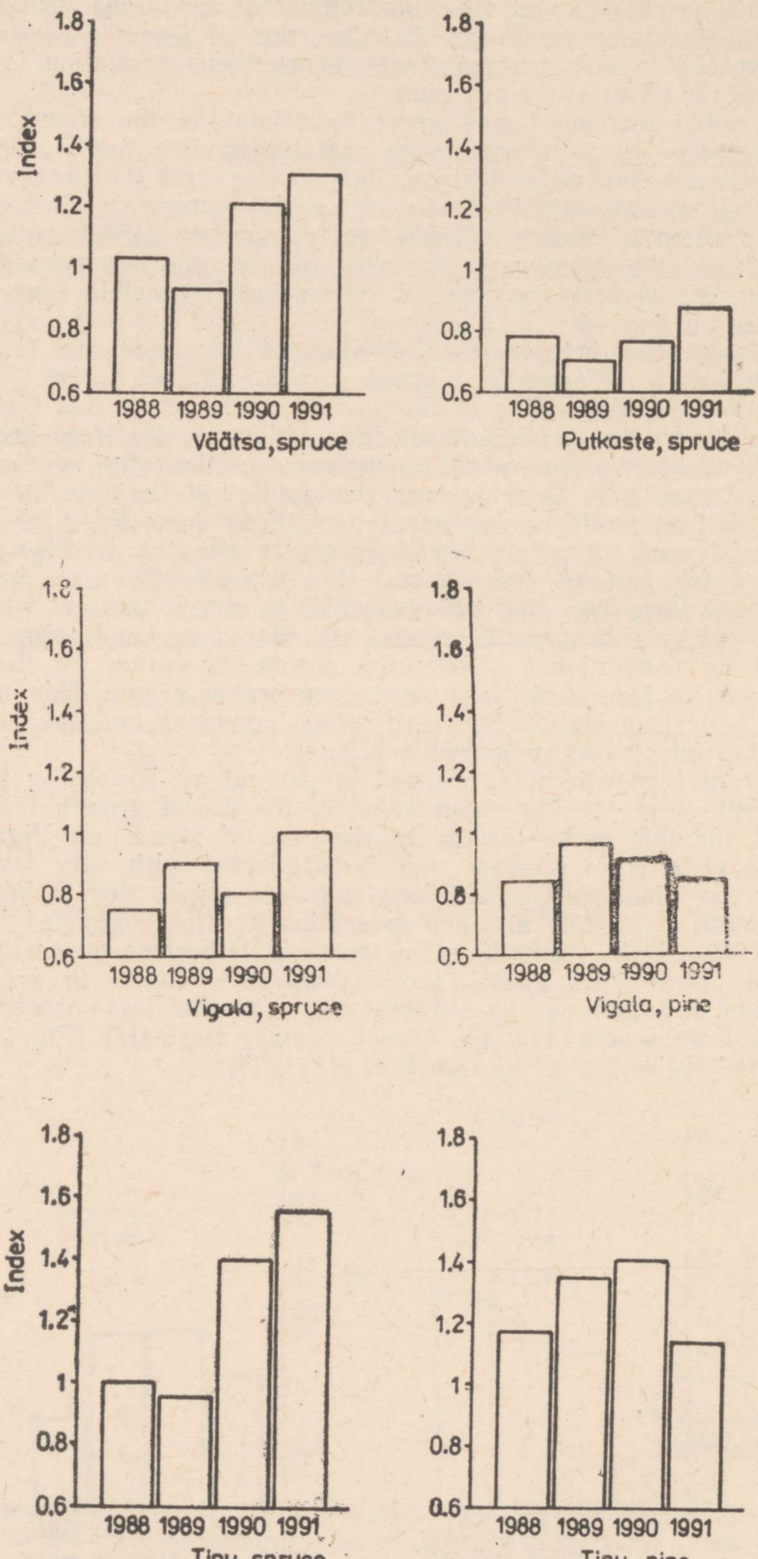

Fig. 1 continued.

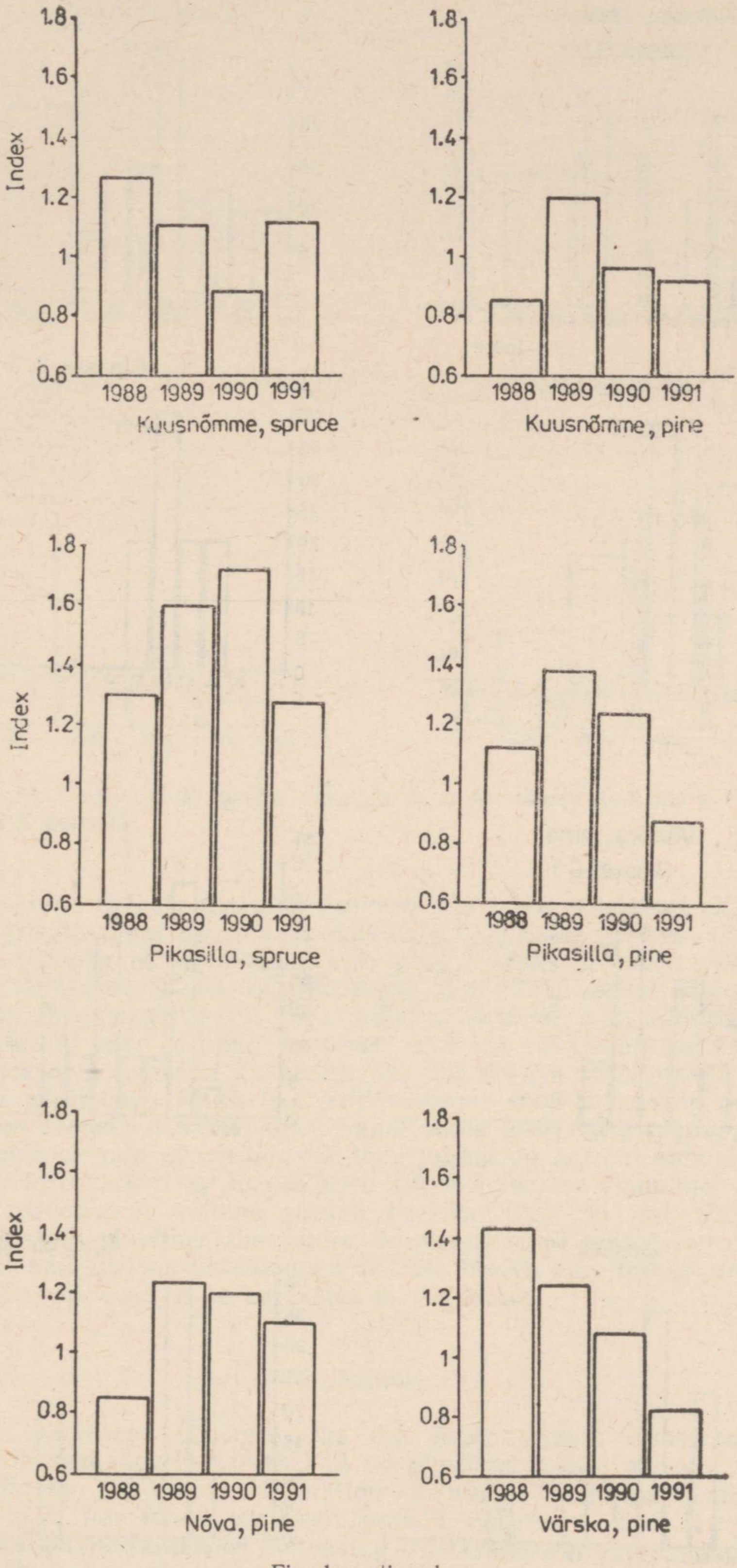

Fig. 1 continued.

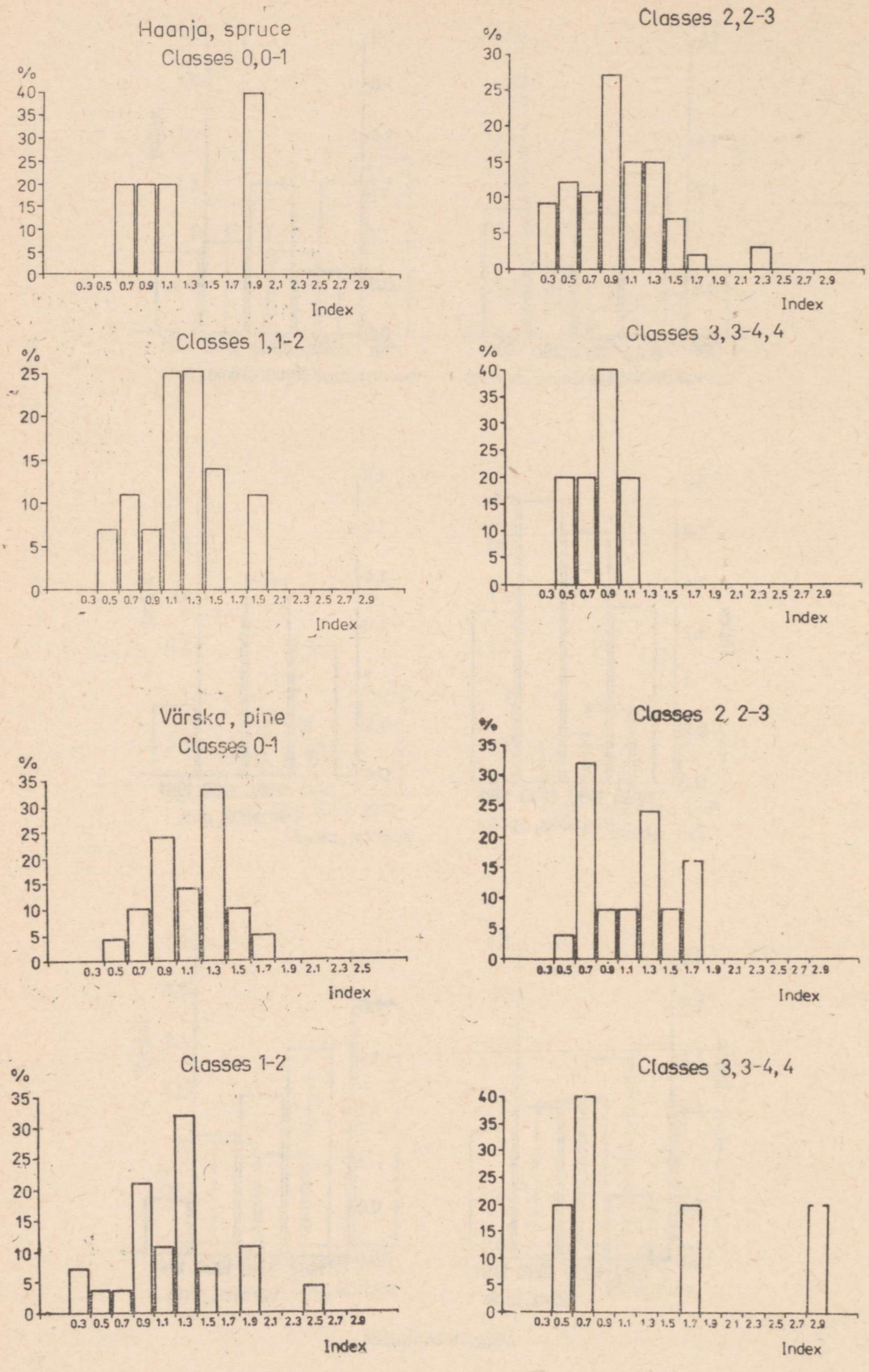

Fig. 2. Distribution of growth indices in crown classes.

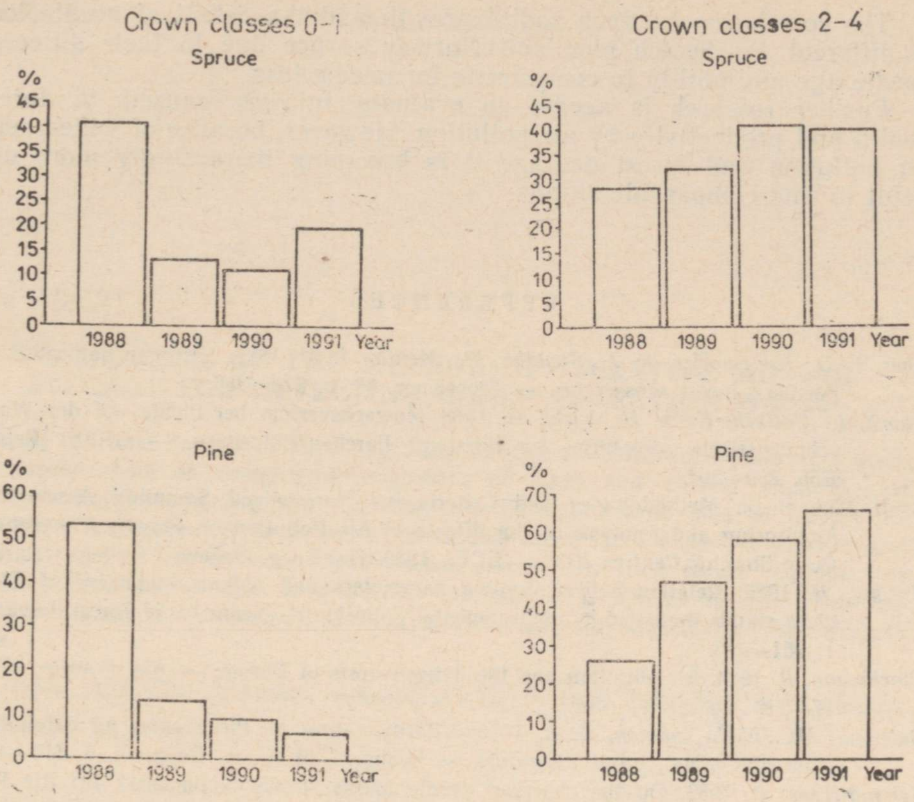

Fig. 3. Percentage of spruces and pines in crown classes 0—1 and 2—4.

Two stands (Vigala plot and Putkaste plot) are at present characterized by growth reduction due to extremely favourable growth conditions (high percentage of soil humus and good drainage), which prolonged the juvenile period in the growth curve; now these stands are passing over to an older stage and so their radial growth has a decreasing trend.

One has to bear in mind, however, that the correlation between the appearance of a tree and its health has not always been proved. There are cases when trees which look still vigorous show a marked decrease of volume growth. On the other hand, some trees which have lost a considerable amount of needles continue producing normal annual rings. It is therefore very risky to use such surveys for the estimation of the possible reduction of volume growth, because they do not allow the prognostication of either the future development of volume growth or the speed and further development of the health of forests and the volume of dead wood to be harvested in the future.

Conclusions

Social conditions of trees like the Kraft growth class and the influence of neighbouring trees had no effect on radial growth.

Statistically significant correlation between defoliation rate and radial growth was found for Kraft growth classes I and II. Radial growth has generally had an increasing trend in recent years; decreasing growth is more typical of pine starting from the 3rd crown damage class.

The correlation between radial growth and the extent of needle loss is different for Scotch pine and Norway spruce due to their different needle age and ability to compensate for needle loss.

Further research is needed to evaluate injuries caused to forest health and productivity by air pollution. However, because of widespread air pollution and forest damage it is becoming increasingly more difficult to find comparable stands.

REFERENCES

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

Bauch, J., Gottsche-Kuhn, H., Riehl, G. 1988. Zuwachsverlust bei Fichte auf der Waldschadensfläche «Posturm» im Forstamt Farchau/Ratzeburg. — GKSS [Rept.], E55, 289—304.

Draft Manual on Methodologies and Criteria for Harmonized Sampling Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests. Programme Co-ordinating Centres /UN — ECE/. 1986. Hamburg, Geneva.

Kramer, H. 1986. Relation between crown parameters and volume increment of *Picea abies* stands damaged by environmental pollution. — Scand. J. of Forest Research, 1, 251—263.

Plochmann, R. 1984. Air pollution and the dying forests of Europe. — Am. Forests, **90**, 6, 17—21.

Salemaa, M., Jukola-Sulonen, E. L. 1990. Vitality rating of *Picea abies* by defoliation class and other vigour indicators. — Scand. J. of Forest Research, 5, 413—426.

Schmid-Haas, P. 1989. Do the observed needle losses reduce increments? In: Air Pollution and Forest Decline. Proceedings of the 14th International Meeting for Specialists in Air Pollution Effects on Forest Ecosystems. IUFRO Project Group P.2.05 Interlaken, Switzerland, 2—8 Oct. 1988. Birmensdorf, 271—275.

Schulze, E. D. 1989. Air pollution and forest decline in a spruce (*Picea abies*) forest. — Science, **244**, 776—783.

Schweingruber, F. H. 1985. Abrupt changes in growth reflected in tree ring sequences as an expression of biotic and abiotic influences. In: Inventoring and Monitoring Endangered Forests. IUFRO Conference, Zürich, 291—295.

Schütt, P., Cowling, E. B. 1985. Waldsterben, a general decline of forests in Central Europe. Symptoms, development and possible causes. — Plant Disease, **69**, 7, 548—558.

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.

Waring, R. H. 1987. Characteristics of trees predisposed to die. — Bioscience, **37**, 8 569—573.

Waring, R. H., Neuman, K., Bell, J. 1981. Efficiency of tree crowns and stemwood production at different canopy leaf densities. — Forestry, **54**, 2, 129—137.

Waring, R. H., Thies, W. G., Muscato, D. 1980. Stem growth per unit of leaf area: a measure of tree vigour. — Forest Science, **26**, 1, 112—116.

Presented by J. Martin, D. Sc.,
Member of the Estonian Academy of Sciences

Received
May 18, 1992