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Forest condition in Finland, 1986–1990

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The results of the Finnish forest condition survey carried out during 1986–1990 in background areas are presented. The same 3388 forest trees (1897 pines, 1289 spruces and 202 broadleaves) on 450 mineral soil sample plots were examined annually. Crown characteristics (defoliation, the number of needle age classes, branch damage and needle discolouration), fertility and abiotic and biotic damage express the general vitality of the trees and are not specific for air pollutants. A correlative approach was applied in analysing the factors which may explain the regional pattern and changes in defoliation.

Average tree-specific degree of defoliation was 9 % in pine, 21 % in spruce and 12 % in broadleaves in 1990. Altogether 11 % of the pines, 42 % of the spruces and 16 % of the broadleaves have lost over 20 % of their needles or leaves. The frequency of defoliated conifers was similar to that in Sweden and Norway. Defoliation in spruce was the same as in the previous year, but in pine and broadleaves it had slightly decreased. Defoliation had increased by 5 %-units in pine, 16 %-units in spruce and 7 %-units in broadleaves during the whole study period 1986–90.

High stand age and different weather and climatic factors greatly affect forest defoliation in background areas in Finland. Pine canker (*Ascocalyx abietina*) has enhanced defoliation in pine in the western part of the country. Air pollutants have evidently contributed to the increase of defoliation in the most loaded parts of South Finland. In pine a significant positive correlation was found between modelled sulphur deposition and the average stand-specific degree of defoliation (Spearman rank correlation $r_s = 0.226$, $P < 0.01$, $n = 194$), as well as with the increase in average 5-year defoliation ($r_s = 0.197$, $P < 0.01$, $n = 187$) in South Finland. It is suspected that green algae growing on needles of spruce in South Finland indicates elevated nitrogen deposition levels.

Tutkimuksessa esitellään tuloksia metsäpuiden yleisestä elinvoimaisuudesta Suomen tausta-alueilla vuosilta 1986–1990. Samat 3388 puuta (1897 mäntyä, 1289 kuusta ja 202 lehtipuuta) tutkittiin vuosittain 450:llä kivennäismaan koealalla. Tutkitut latvustunnukset (harsuuntuminen, neulasvuosikerrat, oksatuhot ja neulasten väriviat), fertiilisyys sekä abioottiset- ja bioottiset tuhot ilmentävät puiden yleistä elinvoimaisuutta eivätkä ole spesifejä ilman epäpuhtauksien vaikutuksille. Tutkimuksessa on käytetty korrelatiivista lähestymistapaa analysoitaessa harsuuntumisen alueellisuuteen ja muutokseen vaikuttavia tekijöitä.

Vuonna 1990 keskimääräinen puukohtainen neulaskato oli männyllä 9 %, kuusella 21 % ja lehtipuilla 12 %. Yli 20 % neulasia tai lehtiä menettäneitä mäntyjä oli 11 %, kuusia 42 % ja lehtipuita 16 %. Havupuiden harsuuntuminen oli yhtä yleistä kuin Ruotsissa ja Norjassa. Edelliseen vuoteen verrattuna kuusen harsuuntuminen pysyi ennallaan, mutta männyn ja lehtipuiden lievästi väheni. Koko tutkimusjakson 1986–90 aikana harsuuntuminen lisääntyi 5 %-yksikköä männyllä, 16 %-yksikköä kuusella ja 7 %-yksikköä lehtipuilla.

Suomen tausta-alueilla puiden harsuuntumiseen vaikuttavat suuresti metsien ikä sekä erilaiset sää- ja ilmastotekijät. Versosurma (*Ascocalyx abietina*) on lisännyt mäntyjen harsuuntumista maan länsiosissa. Ilman epäpuhtauksilla on ilmeisesti ollut vaikutusta harsuuntumisen lisääntymiseen Etelä-Suomen kuormitetuimmissa osissa. Etelä-Suomen mäntyaineistosta löydettiin merkitsevä positiivinen korrelaatio mallitetun rikkilaskeuman ja koealojen keskimääräisen harsuuntumisasteen kanssa (Spearmanin järjestyskorrelaatio $r_s = 0.226$, $P < 0.01$, $n = 194$), rikkilaskeuma korreloi tällä alueella lievästi myös männyn viiden vuoden harsuuntumismuutoksen kanssa ($r_s = 0.197$, $P < 0.01$, $n = 187$). Viherlevän kasvun kuusen neulasten pinnalla Etelä-Suomessa epäillään indikoivan kohonnutta typpilaskeumaa.

Keywords: defoliation, leaves, needle age, discolouration, cones, green algae, air pollution.
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1 Introduction

The extensive forest decline observed in Central Europe in the early 1980s resulted in a need for regional estimates of forest condition based on representative sampling and standardized methods. Since 1985 Finland has participated in the UN-ECE program on forest damage survey. The UN-ECE report publishes statistics concerning the state of health of forests in about 30 European countries. The methods used for vitality assessment in these surveys are visual defoliation and discolouration estimations (Manual on methodologies... 1986). The first survey in Finland was carried out in 1985–86 (Jukola-Sulonen et al. 1987), and annual reports have since then been published in the ECE statistics (Forest damage and air pollution... 1987, 1988, 1989, 1990). A more complete analysis of the vitality of Finnish conifers in 1986–88 was published in the final report of the Finnish Acidification Research Programme (HAPRO) (Jukola-Sulonen et al. 1990a).

The Finnish results from the 1990 nation-wide (extensive level) survey are presented in this paper. The results are compared with annual observations for the whole study period 1986–1990. The aim of this project is to monitor and survey the vitality of forest vegetation in background areas at a national level, and to determine the extent to which air pollution can explain any recorded damage.

Sulo Lehtinen, Jarmo Poikolainen, Heikki Posio and Pekka Suolahti carried out the field survey work. Mauri Timonen created the map programme. Ilkka Taponen drew the tree silhouettes in Figs. 3 and 4. Kari Mikkola, Tiina Nieminen and Aira Byman assisted in many phases of the data handling and in preparing the figures. Päivi Merilä helped us with the algae problem. John Derome checked the English language. Associate Professor Satu Huttunen and Professor Ulf Söderberg commented on the manuscript. We would sincerely like to thank all these persons for contributing to the completion of this paper.

2 Material and methods

2.1 Hierarchical survey design in Finland

Forest condition surveying is carried out on both temporary and permanent sample plot networks. The 8th National Forest Inventory (NFI) comprises 70 000 systematically distributed, temporary sample plots. Defoliation is assessed on 11 000 of these plots (about 40 000 trees). The 8th NFI was started in 1986 and should be completed by 1994.

Permanent sample plots

Systematically distributed, permanent sample plots (3009) covering the whole country were established in 1985–1986 in connection with the 8th NFI (Fig. 1a). The country is divided into a northern and a southern region (demarcation line along latitude 65°). A lower sampling density is used in the northern region. 391 sample plots are located in the north and 2618 in the south. The sampling units in the north are 3-plot clusters arranged in a 32 × 24 km grid, and in the south 4-plot clusters in a 16 × 16 km grid. The actual location of the permanent sample plots is kept secret so that it does not affect forest management. The condition, chemistry and structure of the forest ecosystem on these plots were studied during 1985–86. Tree vitality was studied in conifers by estimating defoliation, number of needle age classes and crown discolouration (Jukola-Sulonen et al. 1987). This network is monitored at 5-year intervals.

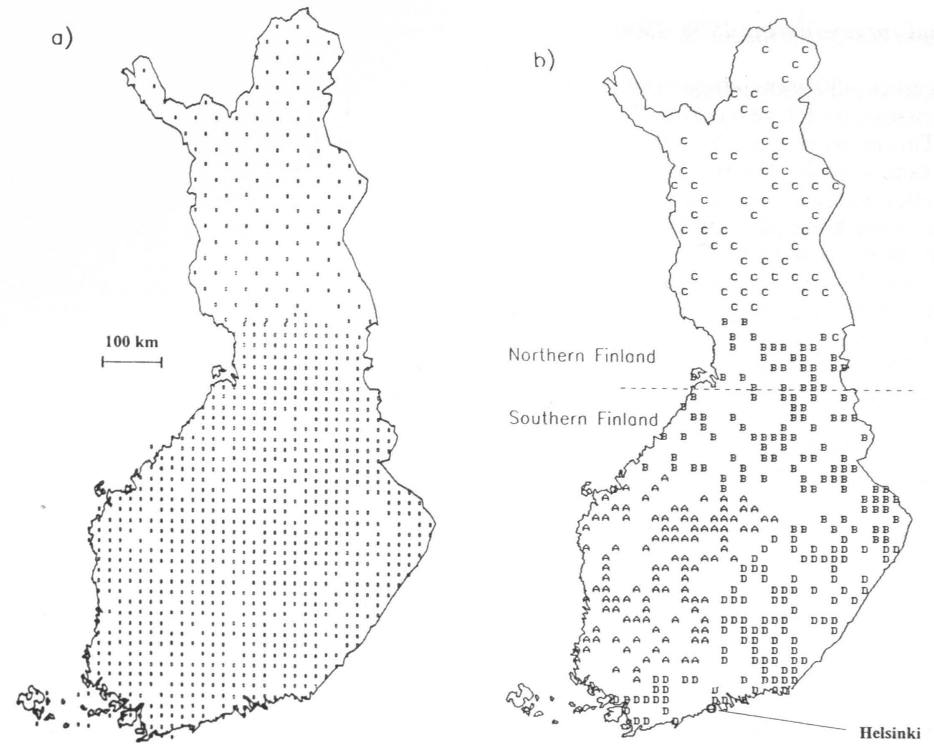


Fig. 1. The networks of permanent sample plots where forest condition is surveyed at different intervals and intensity. a) The 3009 sample plots of the 8th National Forest Inventory. Each point consists of 1–4 plots in southern Finland and 1–3 plots in northern Finland. Surveys are carried out at 5-year intervals. b) Location of the sample plots (n = 450) on mineral soil for annual surveys. The letters A–D refer to the areas surveyed by the four observers. The boundary between southern and northern Finland (latitude 65°) is marked with a dashed line.

Kuva 1. Pysyvien koealojen verkostot, joilla metsien kuntoa seurataan eri aikavälein ja eri intensiteetillä. a) Valtakunnan metsien 8. inventoinnin 3009 koealaa. Jokainen piste sisältää 1–4 koealaa Etelä-Suomessa ja 1–3 koealaa Pohjois-Suomessa. Kartoitukset tehdään viiden vuoden välein. b) Kivennäismaan 450 koealaa, joilla vuosittaiset kartoitukset tehdään. Kirjaimilla A–D on merkitty eri arvioijien inventointialueet. Etelä- ja Pohjois-Suomen välinen raja (leveyspiiri 65°) on merkitty katkoviivalla.

Annual surveys during 1986–1990

Altogether 450 plots situated on mineral soil were assessed each year during 1986–1990 (Fig. 1b). This network is a subset of the 3009 permanent sample plots. The first sample plot in each NFI tract was selected for an annual survey. Of these, every tenth plot and all peatland or treeless plots were omitted. The size of the circular plots was 300 m². All trees with a diameter at breast height of at least 4.5 cm in the dominating crown layer were inspected.

In 1990 3441 of the conifers (*Pinus sylvestris* L., n = 2063 and *Picea abies* (L.) Karst, n = 1378) and 426 of the broadleaves (*Betula pendula* Roth., n = 108, *Betula pubescens* Ehrh., n = 233, *Populus tremula* L., n = 47, others n = 38) were alive. Tree numbers for the different species are lower in the sample consisting of the same trees every year (Table 2). Owing to methodological differences, the annual defoliation results are not comparable with the results of the full survey networks.

2.2 Vitality variables in the annual surveys

The tree vitality variables used in 1986–90 can be classified into five groups: characteristics depicting (A) the amount and variation of the phytomass, (B) crown degeneration, (C) needle and leaf discolouration, (D) fertility, and (E) abiotic and biotic damage (Table 1). Spruce sample branches were selected in 1988 for detailed analysis of needle discolouration and algal growth from trees with accessible branches in the lower crown.

The results presented in this paper mainly concern the year 1990. Defoliation, needle age class and cone crop results from earlier years are also presented. Only defoliation results are included for broadleaved trees owing to their low number. All variables except sample branch parameters were estimated using binoculars. The survey was carried out in July–October. Discolouration in conifers and defoliation in broadleaves were not estimated after August because the normal phenological changes in the colour of the crowns and shedding of the leaves begin. The same four observers assessed the same trees each year. Before the field work the observers underwent a one-week training course.

Defoliation of spruce was estimated on the upper half of the living crown, and of pine and broadleaved trees on the upper 2/3 of the living crown in 10 % classes. The original class values (0, 1, ...9) were changed to the midpoint per cent class values (5, 15,...95 %) in the data analysis. The defoliation pattern of conifers was determined according to Lesinski and Landmann (1988), and the abundance of branch damage according to Westman and Lesinski (1986). The number of needle age classes on conifers was estimated on the upper part of the crown for pine, and on the lower part of the crown for spruce (Table 1). Details of the assessment procedure are given in Jukola-Sulonen et al. (1990a).

Needle discolouration in conifers was estimated in the same part of the crown where defoliation was estimated. Needle-tip yellowing, yellowing and browning were recorded in two needle age classes; current-year needles (produced in 1990) and the older needle generations (produced before 1990). The codes are given in Table 1.

During 1986–1989 the cone crop was estimated on the upper half of the crown where the majority of the cones are to be found. In 1990, however, the cone crop was estimated in the same part of the crown as defoliation (i.e. the upper 2/3 of the living crown in pine and 1/2 in spruce) (Table 1).

Ordinary abiotic (e.g. climatic and anthropogenic) and biotic damage caused by pathogens and herbivores were estimated. The abundance of the pine canker disease *Ascocalyx abietina* was recorded along the roadsides when travelling from plot to plot (Table 1).

Sample branches were selected on 336 spruces. The direction of the sample branch was determined using a compass. Exposure of the branch to sunlight was estimated using a nominal scale (Table 1). Stand density and openings in the crown were the main criteria used in classifying unshaded or shaded branches. Differences in needle colour between the upper and lower sides of the branch were recorded (see e.g. Uhlmann et al. 1989, Fig. 3, p. 5). Discolouration usually occurs on the upper side of branches (Hanisch and Kilz 1991). When the upper side was bleached or had turned brown, the type of needle discolouration was determined (Table 1). Abundance of green algae on the needles was estimated using a three-point scale: none, scanty, abundant (Table 1). Individual algae flecks on a few needles were recorded as a scanty algal growth. If the flecks were joined to form a uniform layer covering over 30 per cent of the needle surface, the growth was classified as abundant.

Table 1. Variables used in monitoring forest condition in Finland in 1990. Defoliation only was estimated on broadleaves.

Taulukko 1. Suomen metsien kunnon seurannassa vuonna 1990 käytetyt tunnukset. Lehtipuista arvioitiin vain harsuuntuneisuus.

A) Amount and variation in phytomass

1. Defoliation
Estimated in 10 % needle/leaf loss classes:

Codes: 0 = 0–10 % defoliation
1 = 11–20 % "
:
9 = 91–100 % "

2. Defoliation pattern
Pine:
Codes: 1 = gap type
2 = uniform type
3 = lower crown type
4 = upper crown type
5 = peripheral (branch-tip) type
Spruce:
Codes: 1 = window type
2 = "larch" (uniform) type
3 = upper crown type
4 = peripheral type

3. Needle age classes (years)
Estimated from the upper crown of pine and from the lower crown of spruce.

B) Crown degeneration

4. Abundance of branch damage

Codes: 1 = no damage
2 = a few dead branches
3 = many dead branches
4 = small openings in the crown
5 = clear openings
6 = severe damage on the lateral branches

C) Needle and leaf discolouration

5. Needle-tip yellowing in current year's needles and in older needle generations
6. Needle yellowing in current year's needles and in older needle generations
7. Needle browning in current year's needles and in older needle generations

Codes: 0 = no symptom
1 = 1–5 % of needles affected
2 = 6–10 % "
3 = 11–25 % "
4 = 26–60 % "
5 = > 60 % "

D) Fertility

8. Number of cones in the part of the crown where defoliation and discolouration were estimated

Codes: 0 = no cones
1 = 1–5 cones
2 = 6–20 "
3 = 21–50 "
4 = 51–100 "
5 = > 100 "

E) Abiotic and biotic damages

9. Cause of injury

Codes: 0 = not identified
1 = wind
2 = snow
3 = other climatic factor
4 = competition
5 = harvesting
6 = other man-made injury
7 = voles
8 = elk
9 = insects
10 = *Peridermium* sp./resin top
11 = other fungi
12 = other vertebrates
13 = saw flies
14 = *Ips* sp.
15 = *Tomicus* sp.
16 = *Heterobasidion annosum*
17 = *Phacidium infestans*
18 = *Ascocalyx abietina*
19 = needle mites
20 = ageing of the trees

10. Severity of the abiotic and biotic damages

Codes: 1 = previous damage
2 = slight damage
3 = moderate damage
4 = fatal

11. Abundance of the fungal pathogen *Ascocalyx abietina* (assessed when travelling from plot to plot).

Codes: 0 = no infections
1 = slight infections on individual trees
2 = slight infections common
3 = severe damage in individual stands
4 = severe damage common

Table 1 continued.
Taulukko 1 jatkuu.

F) Sample branch variables in spruce

12. Exposure of the branch to sunlight

Codes: 0 = shaded branch
1 = unshaded branch

13. Colour difference between the needles on the upper and the lower sides of the branch

Codes: 1 = normal, upper side darker green than lower side
2 = slight difference, upper side light green and lower side darker
3 = clear difference, upper side yellowish green and lower side darker
4 = upper side brownish green and lower side green

14. Type of colour defect (recorded in 13.)

Codes: 1 = needle-tip yellowing (>1/2 mm in the tip)
2 = needle chlorosis
3 = light or yellow flecks on the upper side of the needles
4 = upper side of the needles brownish green or having brown flecks
5 = tip yellowing with chlorosis
6 = tip yellowing with flecking

15. Age of the affected needles

Codes: 1 = current-year needles
2 = previous year's needles
3 = in both above mentioned groups
4 = in older than current-year needles
5 = in older than the 2nd year's needles
6 = in all needle age classes

16. Green algae on the needle surface

Codes: 0 = no algal growth
1 = scanty algal growth
2 = abundant "

G) Others

17. Stand age (yrs) in 1985–86
18. Sulphur deposition (g m^{-2}) based on the model calculations of the Finnish Meteorological Institute

The reliability of the observations based on visual estimation was studied in field tests in 1990. Altogether 24 sample plots (5 % of the total) were reassessed at the end of the field period in September. The four observers independently estimated the defoliation, discolouration and number of needle age classes on pines and spruces.

The average, stand-specific defoliation degree and 5-year defoliation change (1986 vs. 1990) were analysed in relation to stand age and modelled sulphur deposition using Spearman rank correlations. Stand age was determined in 1985–86. Modelled sulphur deposition was based on the calculations of the Finnish Meteorological Institute and the Technical Research Centre of Finland (Tuovinen et al. 1990, Johansson and Savolainen 1990).

3 Results

3.1 Reliability of the results in 1990

The consistency of the defoliation estimations of the four observers was better for pine than for spruce. On the average, 65 % of the pines and 41 % of the spruces were estimated identically by the different observers in tree-specific analysis (for method, see Jukola-Sulonen et al. 1990a). 92 % of the pines and 75 % of the spruces were estimated consistently within an error margin of one class (1 class higher or lower). There was a small systematic error in the results of observer A (western Finland): the pine and spruce estimates were about 0.5 class higher. Correction of this error minimized the differences in defoliation between western and eastern Finland, but the main regional pattern remained unchanged. Because the correction had only a very small effect on the defoliation distributions for the whole country, the results presented in this paper have not been corrected. The personal estimation level of each observer remained very stable between years. This made it possible to monitor annual changes in defoliation rather reliably using uncorrected data.

Estimation of the number of needle age classes was more reliable than the defoliation assessments. The maximum differences in the estimations were 0.4 age classes for spruce (lower crown) and 0.2 age classes for pine (upper crown). No differences were found between the observers (one way ANOVA; pine: $F_{3,627} = 1.91$, $P = 0.120$, spruce: $F_{3,147} = 0.28$, $P = 0.84$). In contrast, the discolouration estimations still need to be improved. Owing to differences between observers, only discolouration distributions for the whole country are presented in this report.

3.2 Defoliation

The whole country 1986–1990

The condition of the same 3388 conifers and broadleaves was monitored during the five-year period 1986–90. Altogether 9 % of the trees were lost during this period, 1.5 % had died and 7.4 % had been cut.

The defoliation frequency distributions were strongly skewed in all years. The majority of the trees were classified into the low defoliation classes (Table 2). According to the Nordic view, defoliation of up to 20 % is regarded as normal variation in the phytomass. The proportion of trees below this defoliation level was 81 % in all species during the five-year period. Spruce was more defoliated than the other tree species.

The age class distribution of the studied pine stands was rather even. The median value occurred in 65-year-old pine stands. The age distribution of the spruce stands was concentrated in over 60-year-old classes, the median occurring at 75 years (Table 3). The proportion of defoliated trees was the higher, the older the stand. In stands older than 60 years the degree of defoliation was also higher (Fig. 2). Defoliation increased in young pine stands during the first three, and in young spruce stands during the first four years.

Frequency of defoliation had increased in all tree species by 9 % units during the five-year period. The increase was 5 %-units in pine,

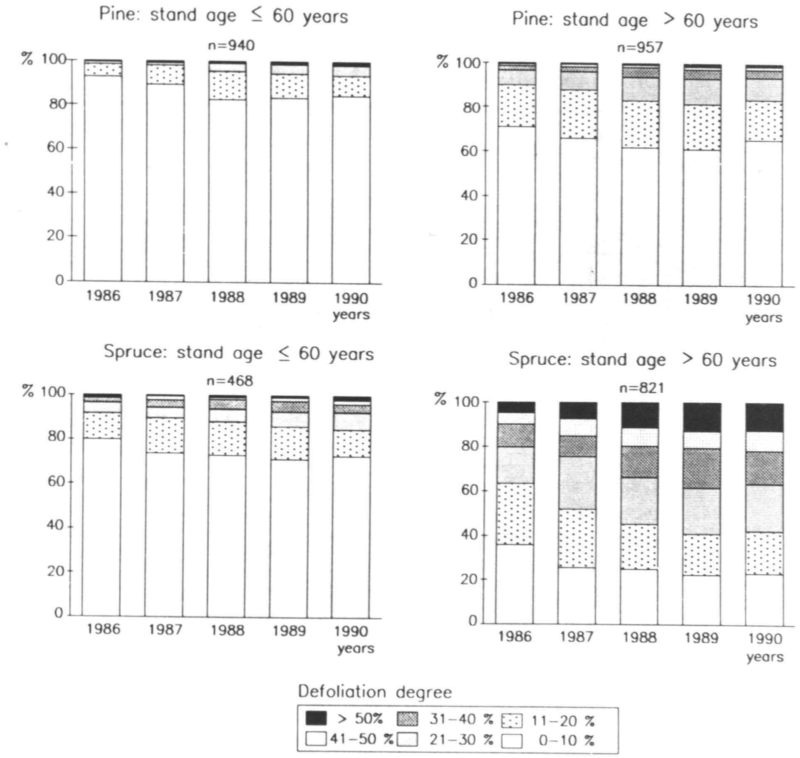


Fig. 2. Defoliation frequency distributions for conifers by 10 per cent needle-loss classes during 1986–1990. The results are given in the two age classes of the stands.
Kuva 2. Havupuiden harsuuntuneisuuden frekvenssijakaumat 10 %:n välein vuosina 1986–90. Tulokset on esitetty alle 60-vuotiaiden ja yli 60-vuotiaiden metsien ikäluokissa.

Table 2. Defoliation frequency distributions of the same trees growing on mineral soil during 1986–90 in the whole country. The table includes only those trees studied in successive years.

Taulukko 2. Kangasmailla kasvavien puiden harsuuntuneisuus vuosina 1986–90 koko maan aineistossa. Tulos perustuu samojen puiden seurantaan viiden vuoden aikana.

Species	Year	n	Defoliation degree 0–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	> 90%
Scots pine	1986	1897	81.8	12.3	4.1	1.1	0.5	0.2	0.1	–	–	–
	1987	"	77.6	15.3	4.8	1.4	0.6	0.2	0.1	0.1	–	–
	1988	"	72.1	17.0	7.3	2.4	0.7	0.3	0.1	0.1	0.1	–
	1989	"	72.2	15.7	8.1	2.5	0.6	0.4	0.4	–	0.2	–
	1990	"	74.8	13.8	7.5	2.2	1.0	0.2	0.2	0.2	0.1	0.1
Norway spruce	1986	1289	51.9	21.6	12.3	7.4	3.3	1.9	0.9	0.4	0.3	0.1
	1987	"	43.1	22.4	16.8	7.2	5.4	2.0	1.7	0.4	0.8	0.2
	1988	"	42.3	18.5	15.3	10.8	5.5	3.7	1.9	0.9	0.9	0.2
	1989	"	40.0	17.3	15.5	13.2	5.4	3.7	2.6	1.1	0.9	0.4
	1990	"	41.0	16.6	16.2	11.0	6.4	3.4	2.6	1.4	1.0	0.5
Broad-leaves	1986	202	85.6	5.4	5.9	2.0	0.5	–	–	0.5	–	–
	1987	"	82.7	9.9	4.5	1.0	1.0	0.5	–	0.5	–	–
	1988	"	69.3	17.3	8.4	2.0	1.0	0.5	1.0	–	–	0.5
	1989	"	63.4	17.3	8.9	5.4	1.5	1.5	1.0	0.5	–	0.5
	1990	"	70.3	13.4	8.4	4.0	2.0	0.5	–	0.5	0.5	0.5
All trees	1986	3388	70.6	15.5	7.3	3.5	1.6	0.8	0.4	0.2	0.1	0.0
	1987	"	64.8	17.7	9.4	3.6	2.4	0.9	0.7	0.2	0.3	0.1
	1988	"	60.6	17.6	10.4	5.6	2.5	1.6	0.9	0.4	0.4	0.1
	1989	"	59.4	16.4	11.0	6.8	2.5	1.7	1.2	0.4	0.4	0.2
	1990	"	61.7	14.8	10.9	5.6	3.1	1.4	1.1	0.6	0.4	0.3

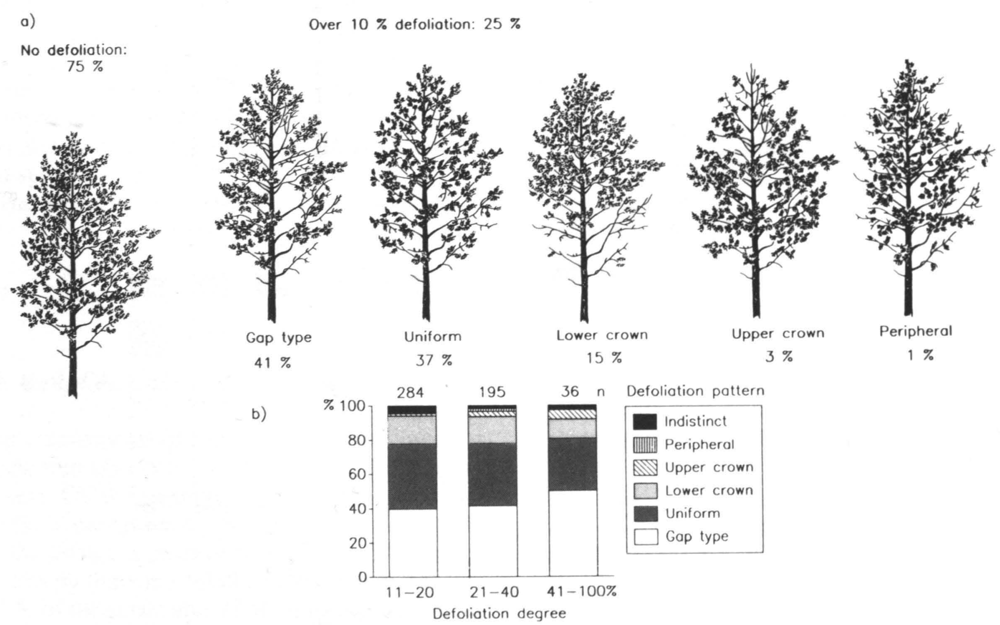


Fig. 3. Defoliation patterns in pine in 1990. a) Frequencies of pine in different defoliation patterns. b) Relationship between defoliation patterns and defoliation degree in pine.

Kuva 3. Männyn harsuuntumistyypit vuonna 1990. a) Eri harsuuntumistyyppien yleisyys (%) männyllä. b) Harsuuntumistyyppien suhde harsuuntumisasteeseen männyllä.

16 %-units in spruce and 7 %-units in broadleaves (Table 2). Defoliation increased every year except for the last one (1990), when the situation remained unchanged or a slight recovery was observed.

Average tree-specific degree of defoliation was 9 % in pine (n = 2063), 21 % in spruce (n = 1378) and 12 % in broadleaves (n = 426) in 1990. The frequency of trees with more than 20 % defoliation was 23 % in all species; 11.4 % in pine, 42.4 % in spruce and 16.3 % in broadleaves.

The most common types of defoliation in pine were the gap type (41 %) and the uniform type (37 %) (Fig. 3a). Lower crown defoliation was often connected with infection by pine canker (*Ascocalyx abietina*, see 3.8) Upper crown defoliation was seldom observed in pines with less than 40 % defoliation (Fig. 3b). The window type (73 %) was the most common defoliation type in spruce (Fig. 4a). The proportion of

Table 3. Age class distributions (%) of the stands at the extensive level. Age class was determined according to the predominant tree species in the dominant storey in 1985–86.

Taulukko 3. Ekstensiivitason metsiköiden ikäluokkajakaumat (%). Ikäluokka on määritetty koealan pääpuulajin valtapuuston perusteella vuosina 1985–86.

Years	Pine (268 sample plots)	Spruce (202 sample plots)
≤ 20	11.9	8.4
21–40	17.2	11.9
41–60	12.7	15.3
61–80	21.6	22.3
81–100	14.9	18.8
101–120	7.1	11.4
> 120	14.6	11.9
	100.0	100.0

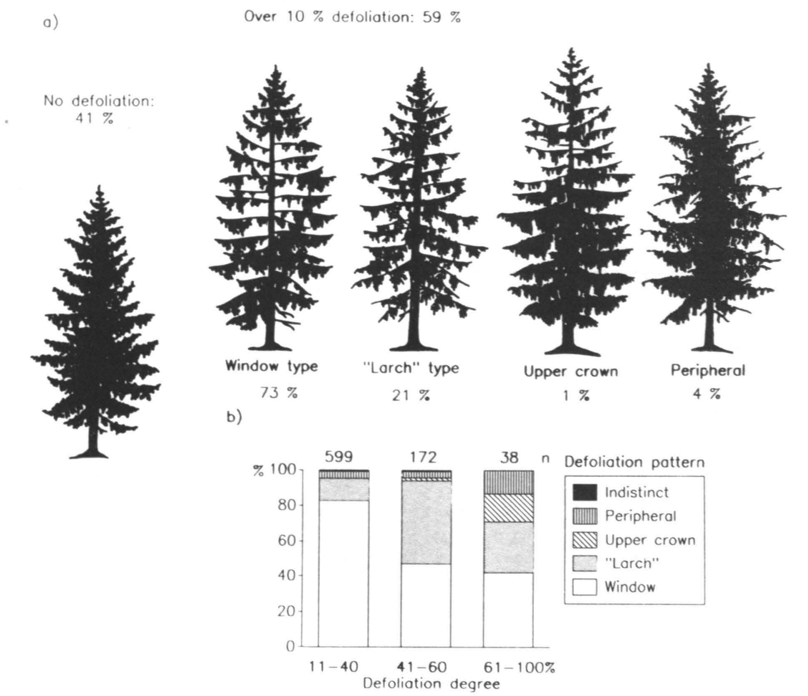


Fig. 4. Defoliation patterns in spruce in 1990. a) Frequencies of spruce in different defoliation patterns. b) Relationship between defoliation patterns and defoliation degree in spruce.

Kuva 4. Kuusen harsuuntumistyypit vuonna 1990. a) Eri harsuuntumistyyppien yleisyys (%) kuusella. b) Harsuuntumistyyppien suhde harsuuntumisasteeseen kuusella.

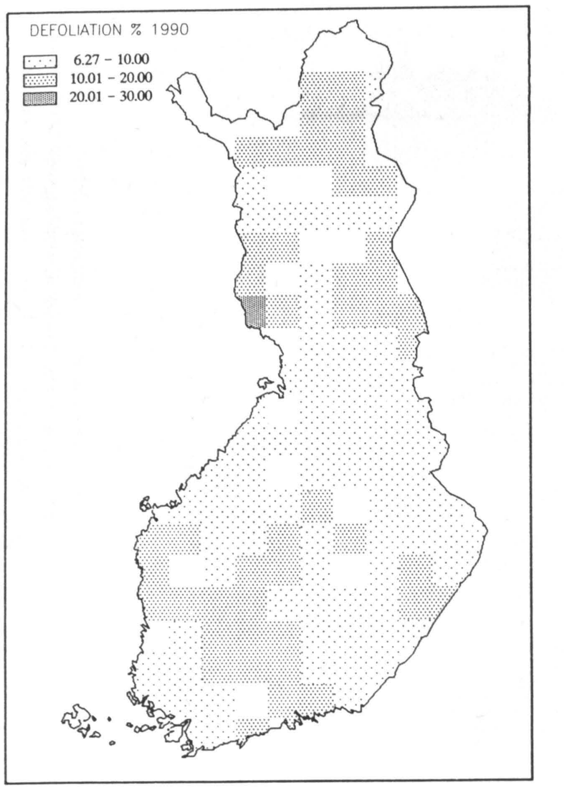


Fig. 5. Defoliation of pine (n = 2063) in 1990 using 50 × 50 km grid averages. Each grid contains an average of 15 and a minimum of 3 pines. Maximum number of pines per grid exceeds 100. White areas indicate missing data.

Kuva 5. Männyn (n = 2063) harsuuntuneisuus vuonna 1990 laskettuna ruutukohtaisina (50 × 50 km) keskiarvoina. Rasteroidussa ruudussa on keskimäärin 15 ja vähintään 3 mäntyä. Enimmillään ruudulla on yli 100 mäntyä. Aineisto puuttuu valkoisilta alueilta.

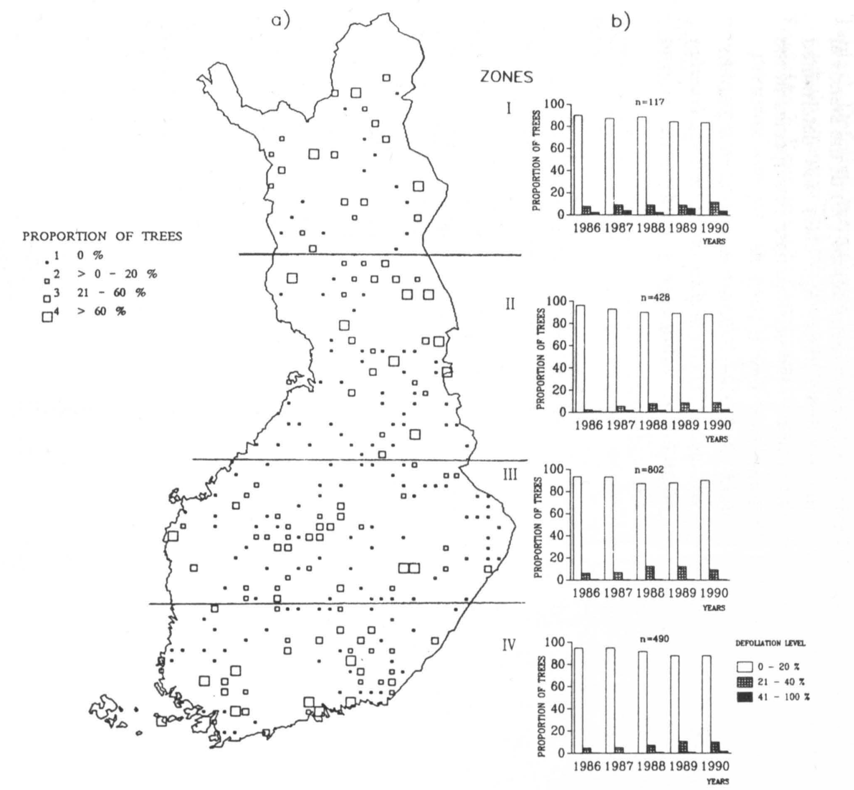


Fig. 6. a) Defoliation of pine in 1990 expressed as the pattern of sample plots with different proportions of defoliated trees. The size of the square indicates the frequency of the trees defoliated > 20 % in each plot. b) Defoliation distributions for pine during 1986–90 in the four latitudinal zones. The light column depicts the proportion of pines with 0–20 %, shaded column 21–40 % and black column > 40 % needle-loss.

Kuva 6. a) Yli 20 % harsuuntuneiden mäntyjen osuudet (%) koealoilla vuonna 1990. Mitä suurempi neliö, sen suurempi osa koealan männyistä ylittää 20 %:n harsuuntuneisuuden. b) Männyn harsuuntumisjakautumat vuosina 1986–90 neljällä vyöhykkeellä. Vaaleat pylväät kuvaavat 0–20 %, tummat 21–40 % ja mustat yli 40 % harsuuntuneiden mäntyjen osuutta.

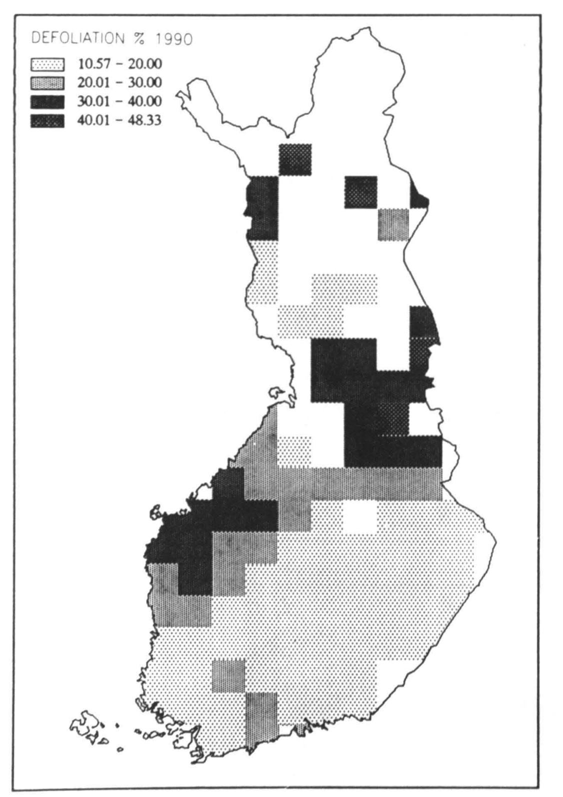


Fig. 7. Defoliation of spruce (n = 1378) in 1990 using 50 × 50 km grid averages. Each grid contains an average of 13 and a minimum of 3 spruces. Maximum number of spruces per grid exceeds 100. White areas indicate missing data.

Kuva 7. Kuusen (n = 1378) harsuuntuneisuus vuonna 1990 laskettuna ruutukohtaisina (50 × 50 km) keskiarvoina. Rasteroidussa ruudussa on keskimäärin 13 ja vähintään 3 kuusta. Enimmillään ruudulla on yli 100 kuusta. Aineisto puuttuu valkoisilta ruuduilta.

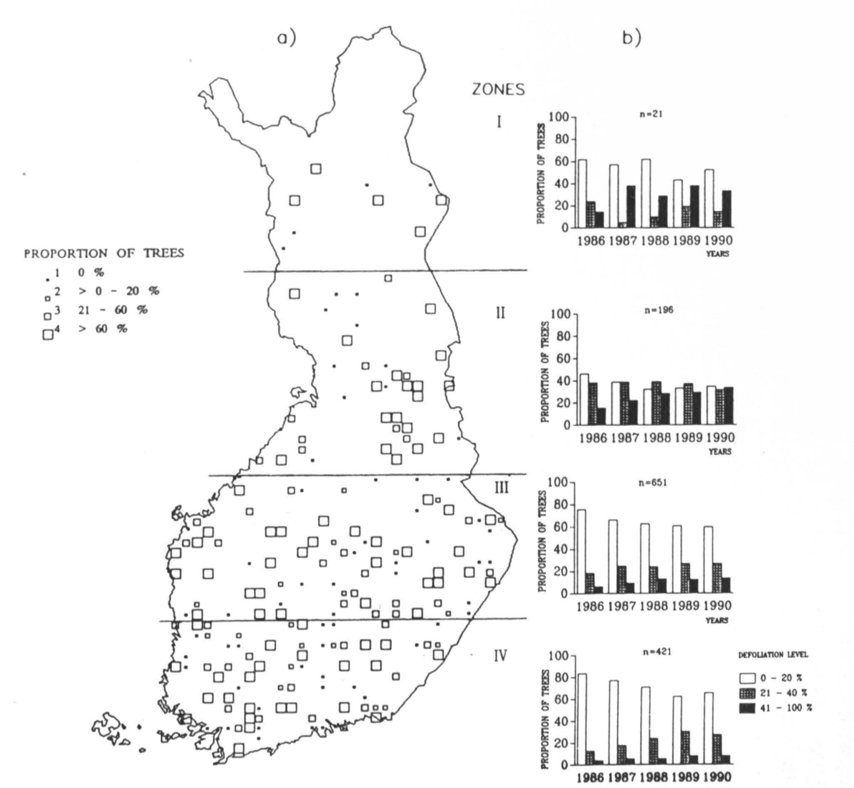


Fig. 8. a) Defoliation of spruce in 1990 expressed as the pattern of sample plots with different proportions of defoliated trees. See details in Fig. 6a. b) Defoliation distributions for spruce during 1986–90 in the four latitudinal zones. See column explanations in Fig. 6b.

Kuva 8. a) Yli 20 % harsuuntuneiden kuusien osuudet (%) koealoilla vuonna 1990. Mitä suurempi neliö, sen suurempi osa koealan kuusista ylittää 20 %:n harsuuntuneisuuden. b) Kuusen harsuuntumisjakautumat 1986–90 neljällä vyöhykkeellä. Vaaleat pylväät kuvaavat 0–20 %, tummat 21–40 % ja mustat yli 40 % harsuuntuneiden kuusien osuutta.

"larch" type increased in spruces with a defoliation degree of over 40 %. Upper crown and peripheral types were recorded only in seriously defoliated spruces (Fig. 4b).

Regionality

The regional pattern of defoliation is depicted in three ways:

(1) Regional averages. The means for defoliation were calculated from the midpoint classes. The size of the grid was 50 × 50 km. This approach may be too general because of the small number of trees in certain areas. In Lapland, especially, the number of spruces is too low (n = 56).

(2) Frequency of defoliation. Regional pattern of sample plots with varying frequencies of over 20 % defoliated trees is presented.

(3) Defoliation distributions in four latitudinal zones in Finland. The distributions are given for five consecutive years.

Grid-average defoliation in pine was strongest in Lapland and in some areas in southern Finland (Fig. 5). The sample plots where most of the trees exceeded the 20 % defoliation limit were situated, besides in Lapland, in SE and SW Finland and in some localities in Central Finland (Fig. 6a). Defoliation in pine increased slightly in northern Finland (zones I and II) and along the southern coast (zone IV), but decreased in the central parts of the country after 1988 (zone III). The frequency of over 40 % defoliated pines was higher in Lapland than in other areas (Fig. 6b).

According to the grid averages, the most defoliated spruces were located in Lapland, Kainuu and Ostrobothnia (Fig. 7). In contrast, the proportion of spruces exceeding the 20 % defoliation limit was high on almost all sample plots (Fig. 8a). When the four latitudinal zones are compared, it is evident that defoliation was most severe throughout the monitoring period in northern Finland (zones I and II). Defoliation in spruce had increased in the whole country from year to year except in 1990 (Fig. 8b).

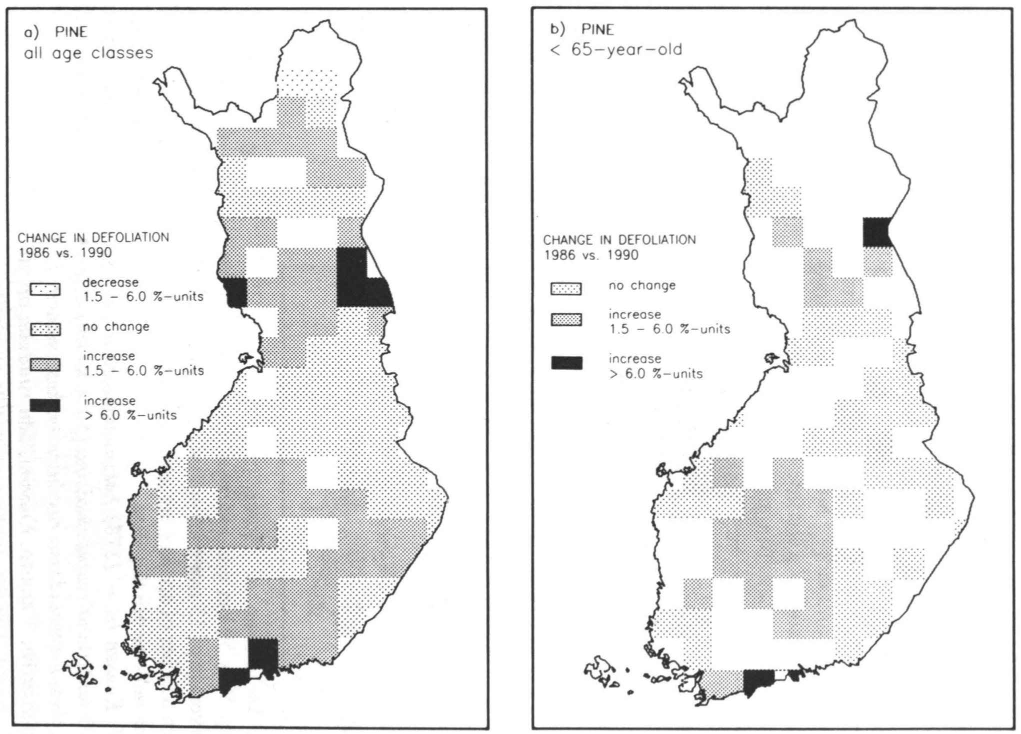


Fig. 9. Changes in defoliation for pine between 1986 and 1990 a) in stands of all ages, and b) in young stands (< 65-year-old).

Kuva 9. Männyn harsuuntumismuutos vuosien 1986 ja 1990 välillä a) kaiken ikäisissä metsissä ja b) nuorissa, alle 65-vuotiaissa metsissä.

Changes between 1986 and 1990

An increase in pine defoliation (> 6.0 %-units in grid averages) was detected in two regions during the 5-year period (1986 vs. 1990): South Lapland and southern Finland (Fig. 9a). Defoliation remained unchanged or slightly increased elsewhere. Defoliation increased (1.5–6.0 %-units) in the central parts of Finland in young, under 65-year-old stands (Fig. 9b).

Defoliation in spruce increased between 1986 and 1990 throughout most parts of the country, especially in Kainuu, southern Ostrobothnia and along the south coast (increase of 7–20 %-units) (Fig. 10a). Defoliation also increased in the southern half of the country in young, under 65-year-old spruce stands (Fig. 10b).

3.3 Defoliation vs. stand age and modelled sulphur deposition

The rank correlations between stand-specific average defoliation in 1990 and stand age were positive ($P < 0.001$) for both pine and spruce in southern and northern Finland. The change (increase) in defoliation between 1986 and 1990 for spruce correlated positively with stand age ($P < 0.001$), too. No corresponding correlation was found for pine (Table 4).

Average stand-specific defoliation and defoliation change (1986 vs. 1990) for pine correlated positively with the modelled sulphur deposition ($P < 0.01$) in southern Finland. No significant correlations were found in spruce (Table 4).

Slight positive correlation ($P < 0.10$) was detected in both pine and spruce between average defoliation and sulphur deposition in the data for under 65-year-old stands in the whole country. However, no correlation was found between defoliation change and sulphur deposition in this age group (Table 5).

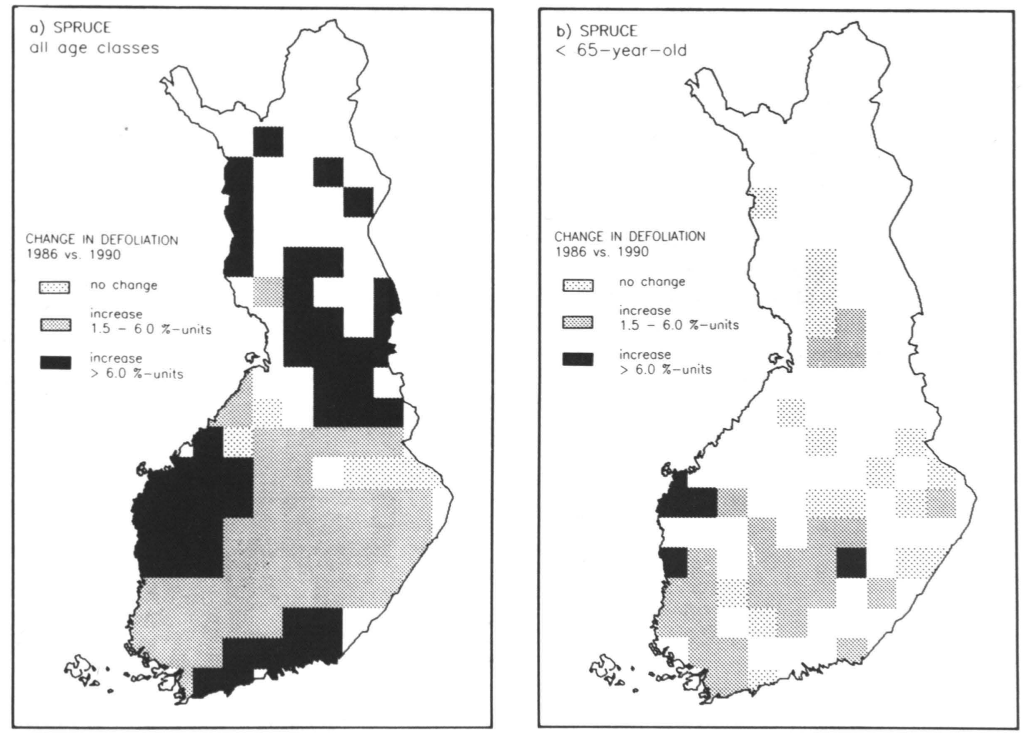
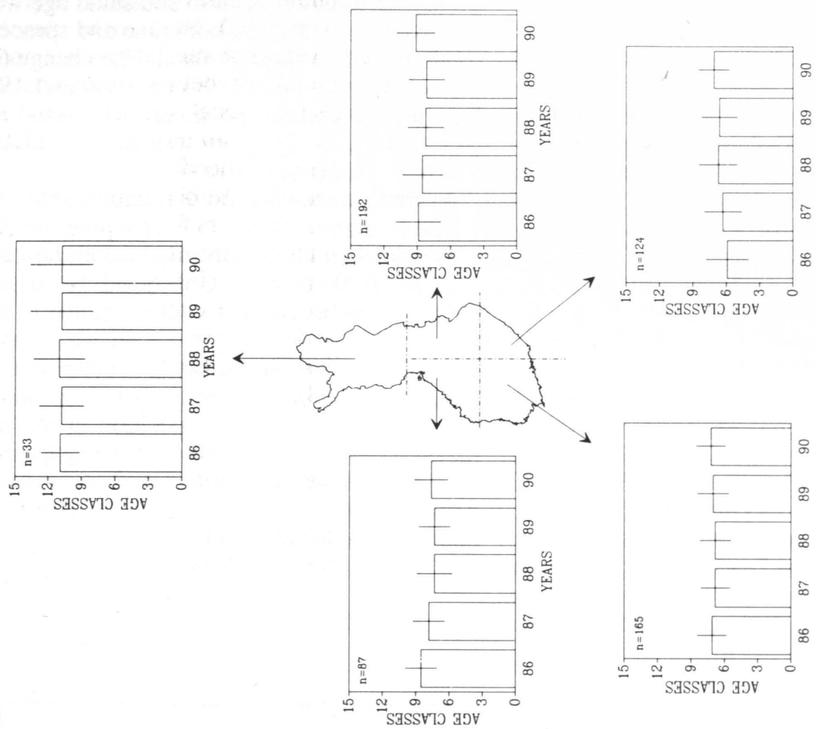


Fig. 10. Change in defoliation for spruce between 1986 and 1990 a) in stands of all ages, b) in young stands (< 65-year-old).

Kuva 10. Kuusen harsuuntumismuutos vuosien 1986 ja 1990 välillä a) kaiken ikäisissä metsissä ja b) nuorissa, alle 65-vuotiaissa metsissä.



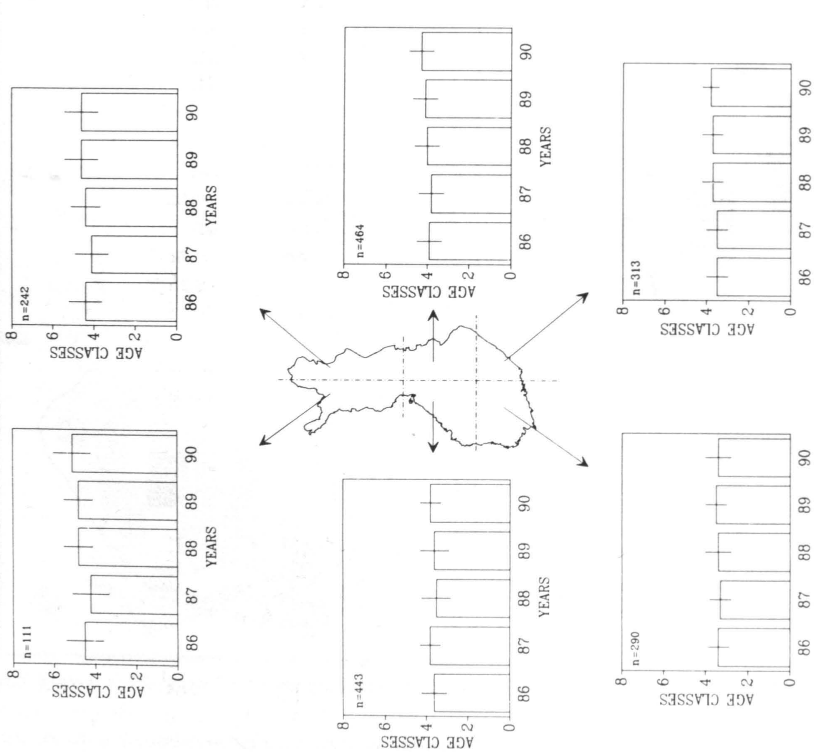


Fig. 11. The number of needle age classes ($\bar{x} \pm sd$) in the upper crown for pine during 1986–1990 in different parts of the country. A needle age class is equal to an annual shoot with at least half of the needles still attached.

Kuva 11. Männyn ylälatvuksen neulasvuosikertojen lukumäärät ($\bar{x} \pm sd$) eri osissa maata vuosina 1986–90. Kokonaiseksi neulasvuosikerraksi luettiin vuosikasvain, jossa oli vähintään puolet neulasista jäljellä.

Fig. 12. The number of needle age classes ($\bar{x} \pm sd$) in the lower crown for spruce during 1986–1990 in different parts of the country. See details in Fig. 11.

Kuva 12. Kuusen alalatvuksen neulasvuosikertojen lukumäärät ($\bar{x} \pm sd$) eri osissa maata vuosina 1986–90. Ks. lisäselityksiä kuvassa 11.

3.4 Needle age classes 1986–90

The number of needle age classes varies naturally between the northern and southern parts of the country. The average number of needle age classes on pine was 3–4 in southern, 3–5 in central and 4–5 in northern Finland (Fig. 11).

Table 4. Spearman rank correlations between average stand-specific defoliation degree and defoliation change (1986 vs. 1990) and modelled sulphur deposition and stand age in a) pine and b) spruce. Southern and northern Finland are dealt with separately (demarcation along latitude 65°). n = number of sample plots. Statistical significance: NS = no significant, ** = P < 0.01, *** = P < 0.001.

*Taulukko 4. Spearmanin järjestyskorrelaatiot koealakohtaisen keskimääräisen harsuuntumisasteen, vuosien 1986 ja 1990 välisen harsuuntumismuutoksen ja mallitetun rikkilaskeuman ja metsikön iän välillä. Etelä- ja Pohjois-Suomen aineistot (raja 65°:n leveyspiirin kohdalla) on käsitelty erikseen. n = koealojen lukumäärä. Tilastolliset merkitsevyydet: NS = ei merkitsevä, ** = P < 0.01, *** = P < 0.001.*

a) Pine

	Sulphur deposition $g\ m^{-2}\ a^{-1}$	Stand age yrs
Northern Finland:		
Defoliation (n = 71)	–0.002 NS	0.691***
Change in defoliation (n = 69)	–0.090 NS	0.192 NS
Southern Finland:		
Defoliation (n = 194)	0.226**	0.448***
Change in defoliation (n = 187)	0.197**	0.086 NS

b) Spruce

	Sulphur deposition $g\ m^{-2}a^{-1}$	Stand age yrs
Northern Finland:		
Defoliation (n = 28)	0.079 NS	0.733***
Change in defoliation (n = 28)	–0.121 NS	0.712***
Southern Finland:		
Defoliation (n = 171)	–0.093 NS	0.737***
Change in defoliation (n = 169)	–0.030 NS	0.446***

The corresponding values for spruce were 6–7, 7–9 and 9–11 (Fig. 12).

There was very low variation in the number of needle age classes between different years within each geographical area. The largest differences were about half an age class. Pine had the lowest number of needle age classes in Lapland in 1987 and in Ostrobothnia in 1988 (Fig. 11). The lowest numbers for spruce occurred in 1986 in SE Finland and in 1989 in the central parts of the country (Fig. 12). The average number of needle age classes ($\bar{x} \pm sd$) in the pooled spruce data (n = 601) was slightly higher in summer 1990 (8.0 ± 1.9) than in the previous year (7.5 ± 1.8).

3.5 Crown degeneration 1990

Crown degeneration was depicted using branch damage. Branch damage describes the abun-

Table 5. Spearman rank correlations between modelled sulphur deposition and average stand-specific defoliation degree and defoliation change (1986 vs. 1990) in a) pine and b) spruce. Correlations are calculated separately for under 65-year-old and over 65-year-old stands. n = number of sample plots. Statistical significance: NS = no significant, ° = P < 0.10.

Taulukko 5. Spearmanin järjestyskorrelaatiot mallitetun rikkilaskeuman ja koealakohtaisen keskimääräisen harsuuntumisasteen ja vuosien 1986 ja 1990 välisen harsuuntumismuutoksen välillä a) männyllä ja b) kuusella. Korrelaatiot on laskettu erikseen alle 65-vuotiaille ja yli 65-vuotiaille metsille. n = koealojen lukumäärä. Tilastolliset merkitsevyydet: NS = ei merkitsevä, ° = P < 0.10.

	Sulphur deposition $g\ m^{-2}a^{-1}$	
Stand age	≤65 yrs	> 65 yrs
a) Pine		
Defoliation	0.158°, n = 136	0.120 NS, n = 151
Change in defoliation	0.071 NS, n = 131	0.069 NS, n = 155
b) Spruce		
Defoliation	0.186°, n = 98	–0.154 NS, n = 129
Change in defoliation	0.114 NS, n = 96	–0.058 NS, n = 127

dance of openings and dead branches in the crown. Branch damage of varying degree was observed on 43 % of pines and 76 % of spruces. The more defoliated the trees, the more serious was the branch damage (Fig. 13).

3.6 Discolouration 1990

Crown discolouration

Every third pine and every second spruce had some kind of discolouration in their crowns. In general, the degree of discolouration was very low, and may be partly caused by normal phenological colour changes even though the estimations were not made after August. Discolouration was very rare in the youngest needles.

Pine: Tip yellowing of the older needles was recorded in 4 %, yellowing in 21 % and browning in 13 % of the pines. Under 10 % of the needles in the crown were affected in 90 % of the cases. Discolouration of this degree is coded as 'none' in the ECE Manual (Manual on methodologies... 1986). Defoliated pines more frequently suffered from needle discolouration than non-defoliated pines. Needle-tip yellowing was most common on poor sites. Needle yellowing occurred evenly on all sites, but needle browning was most frequently observed on moist sites and in rocky areas.

Spruce: Tip yellowing of the older needles was more frequent (in 40 % of the spruces) than yellowing (24 %) or browning (14 %). Only a small proportion (< 10 %) of the needles were affected in 80 % of the cases. As in pine, discolouration in spruce was more common in defoliated trees. Needle-tip yellowing and yellowing were most frequent on moist sites, while needle browning was most frequently recorded on the most fertile sites.

Discolouration of sample branches

Bleaching of the needles on the upper surface of the sample branch was recorded on one third of the 336 spruces studied. Brown discolouration was recorded in 4 % of the cases. A colour difference between the upper and lower sides of the branch was more frequent in the branches exposed to light (41 %) than branches in the shade (22 %) ($X^2 = 11.13$, df = 1, P = 0.001). In contrast, the compass direction of the branch had no effect on discolouration. The bleaching

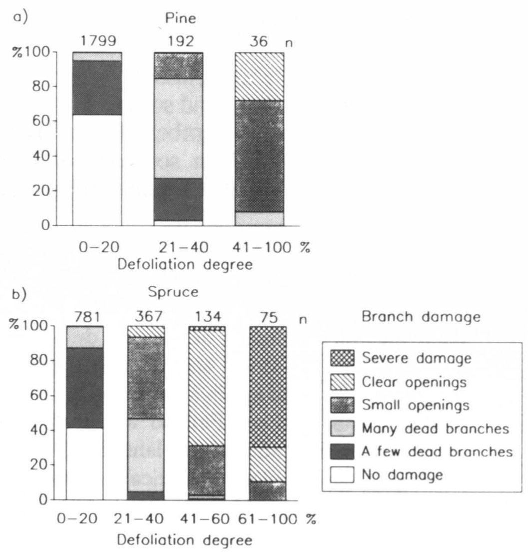


Fig. 13. Severity of branch damage in relation to defoliation degree in a) pine and b) spruce. Data from 1990.

Kuva 13. a) Männyn ja b) kuusen oksatuhojen vakavuus suhteessa harsuuntumisasteeseen. Aineisto vuodelta 1990.

was mainly expressed as chlorosis of over two-year-old needles (58 %). Needle-tip yellowing (21 %) or light flecking (21 %) were also recorded. Needle discolouration on the upper side of the branches was observed locally throughout the country, especially in southern and central Finland. The phenomenon was most common on trees growing on poor sites. On the other hand, degree of defoliation or stand age had no effect on the frequency of this colour defect.

3.7 Coning 1987–1990

The cone yield of conifers varied greatly between years and between areas. In addition to the average cone number per tree, cone yield was affected by the proportion of trees in the stand producing cones in each year. The best cone yield in pine occurred in Lapland in 1988 (Fig. 14). Spruce had a higher cone yield throughout the whole country in 1989 (Fig. 15) when, for instance, the average number of cones (upper 1/4 of the crown) was 70 in dominating spruces in northern Ostrobothnia. There was no covariation between the defoliation degree and

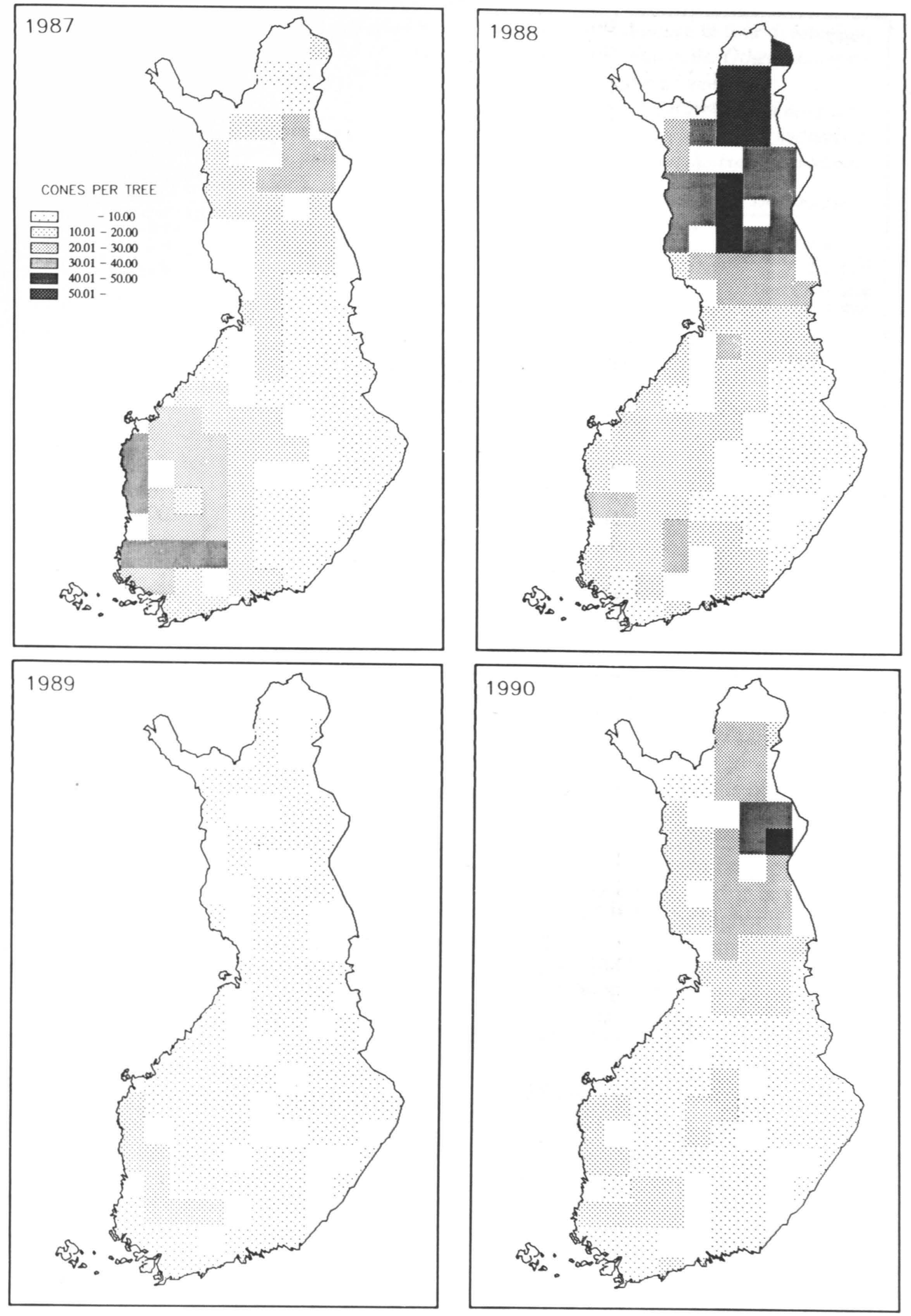


Fig. 14. Cone yield in pine during 1987–1990. The averages are for 50 × 50 km grids. Coneless pines are also included in the averages. Estimation on the upper half (1987–89) and 2/3 (1990) of the crown.

Kuva 14. Männyn käpysato vuosina 1987–90 esitettynä ruutukohtaisina (50 × 50 km) keskiarvoina. Myös kävyttömät puut ovat mukana keskiarvoissa. Arvio tehtiin latvuksen yläpuoliskosta vuosina 1987–89 ja 2/3-osasta vuonna 1990.

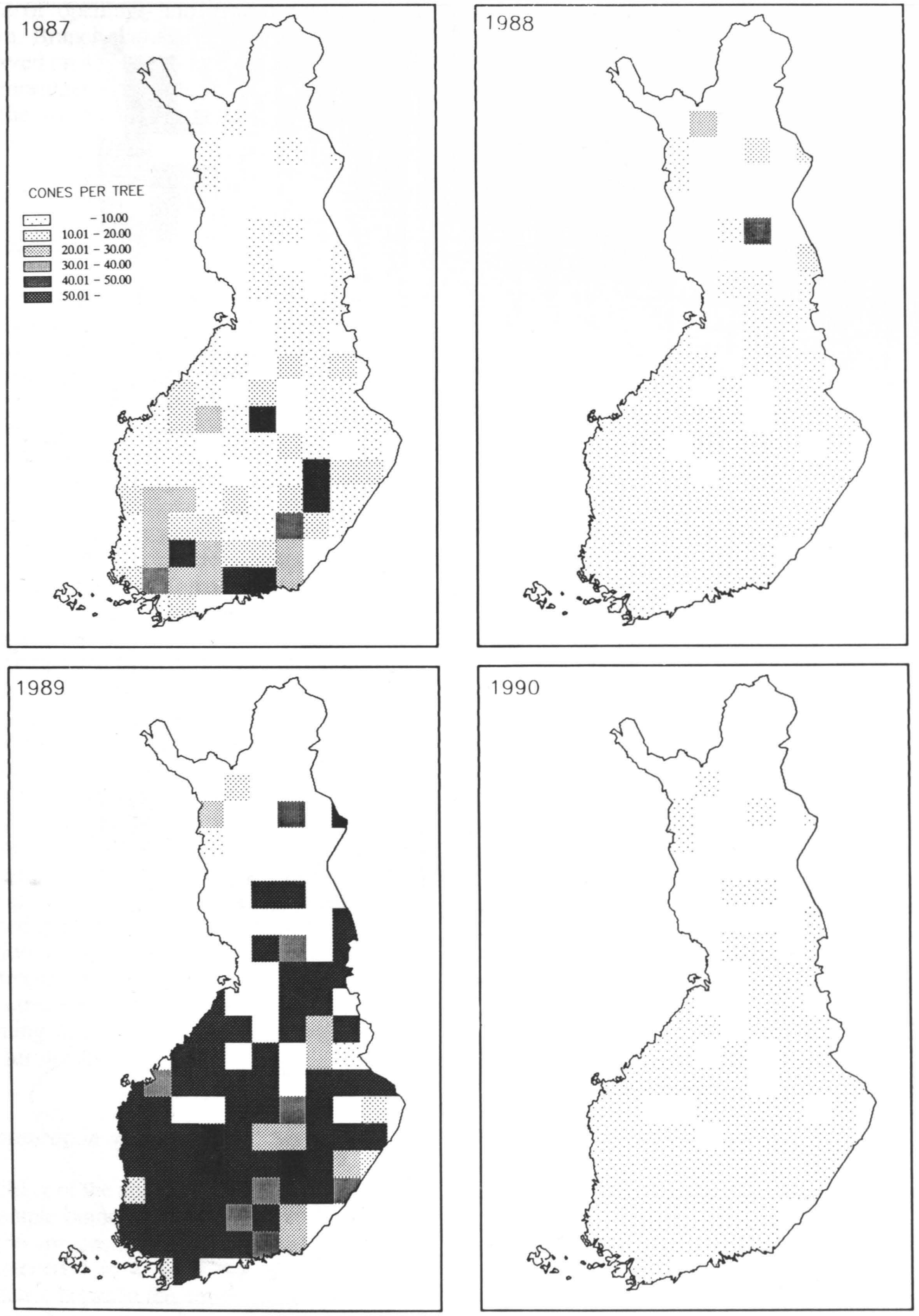


Fig. 15. Cone yield in spruce during 1987–1990. The averages are for 50 × 50 km grids. Coneless spruces are also included in the averages. Estimation on the upper half of the crown.
Kuva 15. Kuusen käpysato vuosina 1987–90 esitettynä ruutukohtaisina (50 × 50 km) keskiarvoina. Myös kävyttömät kuuset ovat mukana keskiarvoissa. Arvio tehtiin latvuksen yläpuoliskosta.

Table 6. Frequency (%) of pines and spruces with abiotic or biotic damage at four defoliation levels. *Abiotic*: wind, snow, frost, etc. *Biotic*: fungi, insects and mammals. *Others*: competition, ageing, harvesting, and other man-made injuries. n = number of trees.
Taulukko 6. Abioottisten tai biootttisten tuhojen yleisyys (%) männyllä ja kuusella eri harsuuntumisasteissa. Abioottiset tuhot: tuuli, lumi, halla jne. Bioottiset tuhot: sienitaudit, hyönteiset ja nisäkkäät. Muut: kilpailu, puiden ikääntyminen, korjuuvauriot ja muut ihmisen aiheuttamat tuhot. n = puiden lukumäärä.

	Defoliation (%)	n	No damage	Not identified	Abiotic	Biotic	Others	Total (%)
Pine	0–20	1835	54.6	4.9	3.5	20.1	16.9	100
	21–40	195	17.4	21.0	10.3	36.4	14.9	100
	41–60	24	8.4	58.3	4.2	20.8	8.3	100
	60–100	12	8.4	0.0	8.3	33.3	50.0	100
Spruce	0–20	801	52.4	8.4	4.1	9.4	25.7	100
	21–40	367	18.2	43.1	7.9	9.5	21.3	100
	41–60	134	0.9	61.9	14.2	2.9	20.1	100
	60–100	76	1.4	60.5	11.8	2.6	23.7	100

the cone number in pine in tree-specific analysis (Fig. 16). In contrast, the cone yield increased with stand age.

3.8 Abiotic and biotic damage in 1990

The frequency of trees with some kind of injury symptom was 49 % for pine and 64 % for spruce. The proportion of trees affected by damaging agents increased with defoliation degree. Among the trees with more than 40 % defoliation, only 1 % of the spruces and 8 % of the pines were unaffected (Table 6).

Competition was recorded as the most common damaging agent for both pine and spruce (30 % of damaged pines and 27 % of spruces). Other important agents were pine canker (*Ascocalyx abietina*) (19 %) and *Tomicus* spp. (12 %) on pine, and fungi (12 %) on spruce. The abundance of fatal and serious damage increased with an increase in defoliation degree (Fig. 17).

Pine canker (Ascocalyx abietina) 1988–90

Pine canker has been a very serious disease in pine forests in Finland during the study period. The epidemic was most severe in western Finland in 1988. The epidemic ceased after 1989, but the disease still exists in certain areas (Fig. 18).

Old or acute symptoms of pine canker infection were observed in 10 % of pines in 1990. Acute infection was recorded in 4 % of pines. These figures concern only pines in the dominating crown layer, and it is probable that the frequencies would be higher if suppressed pines were included. Of the pines classified as having a lower crown defoliation pattern (Fig. 3), 38 % had either previous or acute pine canker.

3.9 Green algae 1990

Altogether one third of the spruces (n = 533) inspected in 1990 had green algae growing on their needles (Fig. 19). Algae were most frequently observed growing on branches facing north, presumably due to the more humid micro-climate. The proportion of algae-infested spruces was higher in stands younger than 40 years and those growing in lush habitats than in older stands and ones in more infertile habitats. The northernmost limit of occurrence of epiphytic green algae in Finland is at the level of Oulu (latitude 65°).

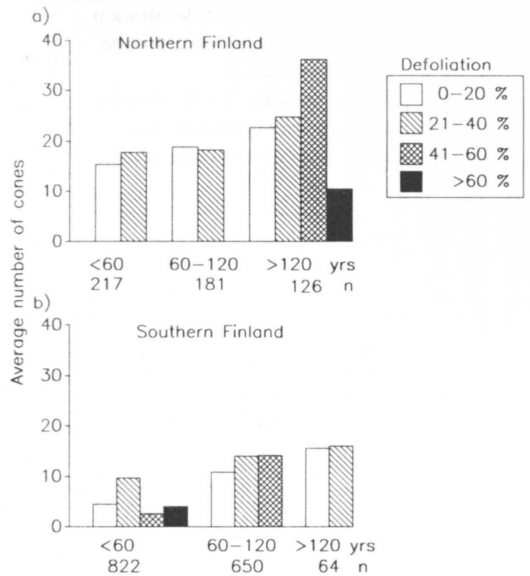


Fig. 16. The average number of cones in pine versus the defoliation degree (columns) and stand age (yrs) in a) northern and b) southern Finland (demarcation line along latitude 65°). Number of pines (n) in different age groups is given. Data from 1990.

Kuva 16. Männyn keskimääräinen käpymäärä verrattuna harsuuntumisasteeseen (pylväät) ja metsikön ikään (yrs) a) Pohjois-Suomessa ja b) Etelä-Suomessa (raja levyspiirillä 65°). n = mäntyjen lukumäärä eri ikäluokissa. Aineisto vuodelta 1990.

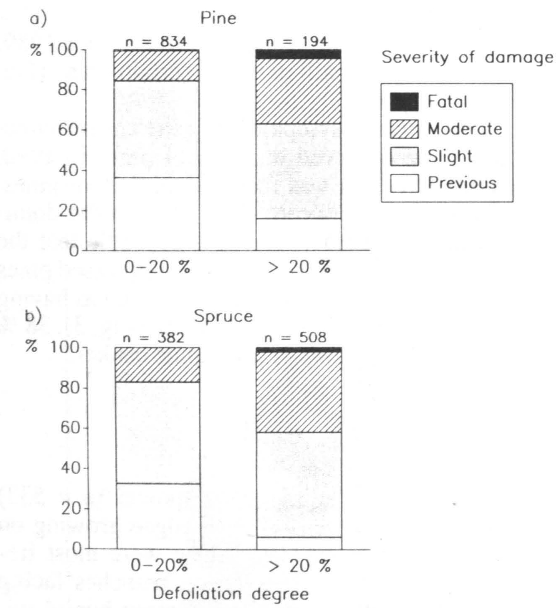


Fig. 17. The severity of biotic and abiotic cases of damage in relation to the defoliation degree in a) pine and b) spruce. Data from 1990.

Kuva 17. Bioottisten ja ei-bioottisten tuhojen vakavuus suhteessa harsuuntumisasteeseen a) männyllä ja b) kuusella. Aineisto vuodelta 1990.

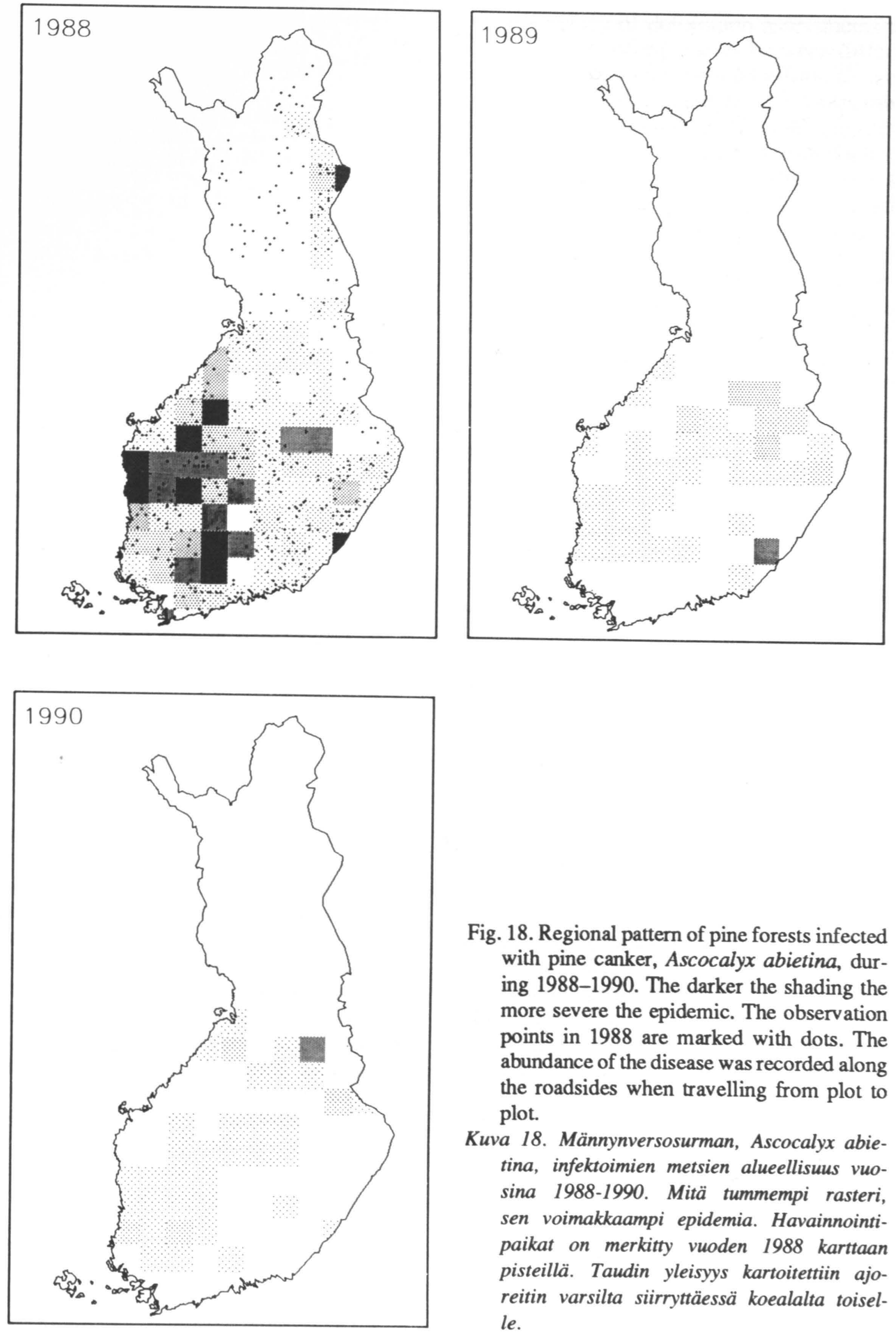


Fig. 18. Regional pattern of pine forests infected with pine canker, *Ascocalyx abietina*, during 1988–1990. The darker the shading the more severe the epidemic. The observation points in 1988 are marked with dots. The abundance of the disease was recorded along the roadsides when travelling from plot to plot.

Kuva 18. Männynversosurman, Ascocalyx abietina, infektoimien metsien alueellisuus vuosina 1988-1990. Mitä tummempi rasteri, sen voimakkaampi epidemia. Havainnointipaikat on merkitty vuoden 1988 karttaan pisteillä. Taudin yleisyys kartoitettiin ajoreitin varsilta siirryttäessä koealalta toiselle.

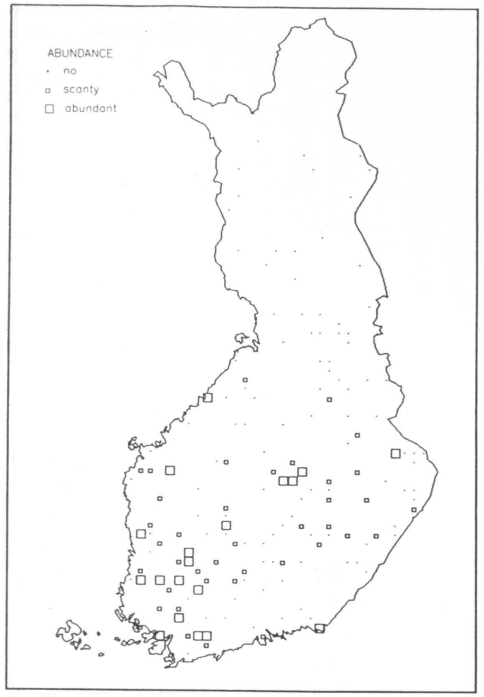


Fig. 19. Regional pattern of green algae (mainly *Apatococcus lobatus*) growing on the needles of spruce in 1990. The size of the symbol indicates the algal abundance.

Kuva 19. Kuusen neulasilla kasvavan viherlevän (pääasiassa Apatococcus lobatus -lajia) alueellisuus vuonna 1990. Pieni neliö ilmentää niukkaa leväpeitettä ja suuri runsasta leväpeitettä.

4 Discussion

4.1 Methodology

Defoliation and needle yellowing were the two visible symptoms initially described in the context of forest decline in Central Europe (e.g. Krause et al. 1983, Schütt and Cowling 1985). The amount of needle or leaf biomass and its variation express the overall vitality of trees and they are affected by a wide range of factors. Besides aging of the tree and natural stresses caused by climatic (frost, drought, wind) and biotic factors (insects, fungi), defoliation is also attributable to the direct or indirect effects of air pollution. The main reasons vary in each stand depending on the level of pollutant deposition, the geographical location, the season and the age and sensitivity of the trees (Klein and Perkins 1987, Schulze and Freer-Smith 1991).

One major problem in using general vitality indices is the reliability of the visual observations (Innes 1988, Innes and Boswell 1989, Jukola-Sulonen et al. 1990). Despite training, defoliation and discolouration estimations of standing trees are always subjective and may contain considerable error variation. Stand density, weather and illumination all affect the estimation. It is important that the individual estimation level remains constant throughout the monitoring period. In this study the same four observers assessed the same trees every year, which improves the comparability between different years.

Visible symptoms are restricted to current damage only. However, they are less suited for predicting vitality changes. For example, many biochemical and cytological changes precede crown discolouration and defoliation (Malhotra and Khan 1984), and these changes could be used as "early warning" symptoms (Ratsep 1991). More specific indicators in extensive monitoring can help to distinguish between air pollutants and other stress factors in forest damage (Huttunen 1988a, Thomsen 1989).

The variables used to characterize tree condition reflect both the seasonal cycle and the latitudinal gradient in Finland. In addition, they are indicators of different anthropogenic stress factors. This means that annual or long-term changes in condition variables are presumably more informative measures of tree vitality than mere demonstrations of large-scale gradients.

The following uncertainties in the data must be taken into account when interpreting the results: 1) the number of trees is rather low, especially in Lapland, for making regional generalizations, 2) the subjectivity of the visual estimations introduces error variation in the data, and 3) phenological events may be confused with stress symptoms. A correlative approach is used to identify covariation between different phenomena. If there is a clear spatial or temporal association between the expression of damage symptoms in vegetation and pollution exposure, it is probable that air pollutants are the causal agent. However, the existence of covariation is not sufficient evidence to elucidate causality (Ashmore 1988). Experimental research is needed to demonstrate the response of vegetation to environmental change.

4.2 Defoliation in other countries

The defoliation level of conifers in Finland was similar to that in Sweden (Wulff and Söderberg 1991) and Norway (Overvåking av skogens ... 1991). In these countries, about one fifth of the conifers were defoliated by over 20 %, which represents an intermediate level considering the whole Europe. In the countries with the most severe forest damage such as Czechoslovakia or Poland, the corresponding defoliation level was 70 % and 48 % respectively (Forest damage and air pollution... 1990). Defoliation of conifers and broadleaves was more common in Denmark than in Finland (De danske skovens... 1991). However, it is difficult to compare these two countries because of the differences in climatic conditions and tree species composition. In Sweden the condition of broadleaves (Söderberg and Wulff 1990) was studied only in the southern part of country in 1990. Altogether 17 % of the birches (*Betula pendula* and *B. pubescens*) were recorded to have over 25 % leaf loss (Wulff and Söderberg 1991). This is almost the same level as for all broadleaf species in Finland (16 %).

The accuracy of defoliation assessments and forest damage records varies between different countries despite international efforts to standardize the methods. Therefore the comparability of the data collected in different countries is nowadays critically evaluated (Forest decline ... 1990). Because the structure of the canopy and the crown morphology vary inside the distribution range of tree species, the same degree of defoliation has different meaning in different regions. In addition to variation in climatic conditions, species composition and silvicultural practices, patterns of pollution deposition differ markedly between countries. This makes it difficult to compare forest condition in different areas (Schulze and Freer-Smith 1991).

The following factors have been found to characterize the high degree of forest defoliation recorded in Europe when the damage clearly attributable to the air-pollution point sources is excluded. Needle loss is mostly concentrated in old stands and at high altitudes. It is also often associated with stands growing on sites with lower water retention capacity and unfavourable nutrient conditions. Furthermore, a harsh climate and unsuitable silvicultural treatment enhance defoliation. Sensitive tree species, the dominating trees in a stand and the edges of stands are most affected (Forest decline ...1990). Of the countries participating in the UN-ECE Forest Damage Survey, eight consider air pollution to be the essential factor destabilizing forest health, and the others (e.g. the Nordic countries) suggest that air pollution is a factor contributing to the deterioration in forest health (Forest damage and air pollution... 1990).

4.3 Factors affecting defoliation in Finland

Forests defoliation increased in Finland during the study period, apart from in the last year (1990). The most defoliated conifers were found in Lapland, Kainuu and Ostrobothnia. The defoliation increase between 1986 and 1990 was also the greatest in these areas and along the southern coast. Only the heaviest defoliation was seen as a regional decrease in the number of needle age classes. The agents causing for the variation in forest condition varied in different parts of the country, and in different years. Intercorrelations between the explanatory variables (stand age, latitude, pollution gradient) make it difficult to identify the causal relationships.

A five-year monitoring period is too short to draw any firm conclusions about the condition of Finnish forests. Long-term needlefall series (Kouki and Hokkanen 1992), as well as studies on needle vascular bundles (Jalkanen and Kurkela 1990), show that annual variation in the needle mass of trees has always been very high. On the individual tree level, defoliation degree correlates negatively with growth (Nöjd 1990, Salemaa and Jukola-Sulonen 1990). However, no adverse long-term changes in the growth of forests have been documented in Finland (Nöjd 1990).

Climate and stand age

According to the results of five-year monitoring work it would appear that the defoliation of forest trees in the background areas of Finland is greatly affected by natural factors such as high stand age and the severe climate. The correlation between stand age and defoliation degree was higher in spruce than in pine. A northerly location also enhanced defoliation. These factors have been found to explain defoliation in Sweden (Anderson 1988, Wulff and Söderberg 1990) and Norway (Overvåking av skogens ... 1991), too. The effect of weather conditions is discussed in Jukola-Sulonen et al. 1990. Climatic stress may predispose conifers to air pollutants, especially at low temperatures (Huttunen 1984, Huttunen et al. 1990).

Air pollution

Forest ecosystems in Finland are affected adversely by sulphur dioxide, nitrogen compounds and their atmospheric transformation products, acid precipitation and ozone (Kenttämies 1991). The proportion of sulphur has decreased and the proportion and amounts of nitrogen compounds have increased during the 1980s (Air quality management... 1989). The acidification of rain water has increased continually during the last decade (Järvinen and Vänni 1990, Laurila 1990).

No clear connections were found on the national level between the regional distribution of forest defoliation and the pollution load. However, when northern and southern Finland were analysed separately, slight covariation was found between defoliated pine stands and the modelled sulphur deposition in southern Finland. The average increase in pine defoliation between 1986 and 1990 also correlated with sulphur deposition in this area. The most seriously defoliated, less than 65-year-old conifer stands were located in southern Finland, which also has the highest sulphur and nitrogen deposition levels. It is concluded that air pollutants have evidently contributed to the increase in defoliation in the most heavily loaded parts of South Finland. However, a statistical correlation does not prove causality. For example, the pine canker epidemic was the severest in the same area. The disease alone or its interaction with other factors may partly explain the observed pattern and change in defoliation.

The abundance and species composition of some epiphytic lichens and their time-series provide evidence about the influence of air pollutants on forest ecosystems in southern Finland. The low IAP values and scarcity of *Usnea* and *Bryoria* species, as well as the decreased frequencies of these species, may indicate long-term detrimental effects of sulphur deposition (Kuusinen et al. 1990). Sulphur and nitrogen accumulation in *Hypogymnia physodes* were at their highest in the southern parts of the country in 1985–86 (Kubin 1990).

Concentrations of atmospheric sulphur compounds are the highest during the winter months (Kulmala et al. 1990). The interaction between air pollutants and freezing temperatures might be crucial for coniferous forests under northern conditions (Huttunen et al. 1983). The long-term effects of low concentrations of pollutants may represent an additional stress for forest trees also in background areas. The accumulation of pollutants on needle surfaces in the winter has been found to cause erosion of stomatal waxes and to disturb the water balance of needles (Huttunen and Laine 1983, Huttunen et al. 1985, Karhu and Huttunen 1985, Tuomisto 1988). Different wintering stages (hardening, dormancy and postdormancy) might be disturbed under air pollution stress (Huttunen 1984). Defoliation of young pine stands in some areas in western Finland may be connected with nutrient-poor soils that are susceptible to acidic deposition (Raitio 1990).

Some surveys carried out in urban areas (Mäkinen et al. 1989, 1991, Jukola-Sulonen et al. 1990b) and around point sources (Huttunen 1988b, Manninen et al. 1990, Jussila et al. 1991) in Finland indicate that air pollutants may be one important factor causing defoliation at a local level. Mäkinen et al. (1991) found that correlation between the defoliation degree and the modelled pollution load ($SO_2 + NO_x$) was higher in pine than in spruce in the Helsinki region.

Results about the relationship between air pollutants and the spatial distribution of defoliated forests are contradictory. In Sweden, defoliation increases on moving northwards as the pollutant load decreases. Although soil acidification is enhanced due to acidic deposition in the southern parts of the country (Falkengren-Grerup and Osswald 1988), no statistically significant covariation has been found between the defoliation of trees and pH values in the soil (Nihlgård 1989). However, air pollutants are considered to be one factor contributing to serious defoliation in southern and SW Sweden (Bengtson 1987). In the United Kingdom, Innes and Boswell (1989) have found no clear indication that air pollutants adversely affect forest condition. Instead, the crown density of four tree species was greater in those areas where atmospheric pollutant concentrations were higher. Only increasing levels of ozone seemed to decrease crown density in Scots pine. Tree age, soil and climatic variables correlated most frequently with crown condition parameters. Contrary to the situation in the UK, pollution-related defoliation has been reported from Germany (Schulze and Freer-Smith 1991). The area of damaged Norway spruce per growing district was associated with increased wet deposition of sulphate and nitrate pollutants or the average summer ozone concentration.

No covariation was found between tree-specific coning and defoliation degree in pine in this study. Similar results are reported for spruce in Switzerland (Stutz et al. 1987) and in Germany (Krug 1989). However, there is evidence that air pollutants have detrimental effects on essential phases in the sexual reproduction of trees. For example, pollen germination was reduced and pollen tube growth was inhibited under simulated acid rain treatments (Cox 1983, Sidhu 1983).

4.4 Other stress indicators in Finnish forests

On the whole, extensive needle discolouration was observed rarely. This corresponds to the situation in Sweden, too (Wulff and Söderberg 1991). In the detailed screening of spruce sample branches, the most common discolouration symptoms were chlorosis and tip yellowing of older (> 2-year-old) needles. These symptoms were more frequent on the upper side of the branches and on branches exposed to sunlight. Although the symptoms are far from alarming, they must be monitored continually. Phenotypically similar, but more severe colour defects of needles, are typical of spruces growing in forest decline areas in Central Europe (Uhlmann et al. 1989, Hanisch and Kilz 1990). Chlorosis may be due to oxidative processes in the light-dependent pigment bleaching of the needles (Elstener and Osswald 1988). Connections between these symptoms and nutrient disturbances, e.g. magnesium deficiency (Zöttl and Hüttl 1989), and the occurrence of elevated ozone levels (Prinz et al. 1985, Brown et al 1987, Sutinen 1990) or adverse weather factors, require more detailed study.

Pine canker (*Ascocalyx abietina*) was the only pathogen which clearly contributed to the increase in regional level defoliation (Nevalainen and Yli-Kojola 1990). The poor condition of the trees seemed to be expressed as a multistress symptom. The most defoliated trees suffered simultaneously from branch damage, discolouration and different type of abiotic and biotic damage.

Owing to their high growth rate, single-celled green algae may react more rapidly to environmental changes than the more developed plants such as trees. The algae were isolated in laboratory cultivations in 1990 (pers. comm. Päivi Merilä, University of Helsinki, Department of Environmental Conservation). The main species in the pure cultures was identified from photographs as *Apatococcus lobatus* (pers. comm. Georg Gärtner, University of Innsbruck, Department of Botany). Abundant algal growth is known to indicate elevated nitrogen deposition levels, at least in southern Scandinavia (Göransson 1990). The mild winters and wet autumns during the past few years have undoubtedly also promoted the increased growth of algae in Finland. Nitrogen deposition in the growing range of the algae is over 6 kg/ha both in Finland (measurements of the National Board of Waters and the Environment, Järvinen and Vänni 1990) and in Sweden (Göransson 1990). The estimated critical annual load for nitrogen in coniferous forests, although varying greatly between habitats, is 3–15 kg/ha (Nilsson and Grennfelt 1988, p. 20).

5 Conclusions

At present, it is very difficult to distinguish the effects of air pollution from those of climate and disease or their interaction on forest trees in background areas in Finland. However, defoliation of the tree crowns and some discolouration symptoms on branches, as well as algal growth on needles, are all early symptoms of forest decline phenomena. Covariation between the average defoliation degree and modelled sulphur deposition indicates that air pollutants have contributed to the increase in defoliation in southern Finland at least.

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Seloste

Suomen metsien elinvoimaisuus vuosina 1986–1990

Tutkimuksessa esitetään tuloksia metsäpuiden yleisestä elinvoimaisuudesta 450:llä kivennäismaan koealalla Suomen tausta-alueilla vuosilta 1986–1990. Vuonna 1990 puita oli elossa 3867 (2063 mäntyä, 1378 kuusta, 108 rauduskoivua, 233 hieskoivua, 47 haapaa ja 38 muuta lehtipuuta). Otoskoko pienenee 3388:aan, kun vain sellaiset puut, joista on tietoja tutkimuskauden jokaiselta vuodelta, ovat mukana.

Puiden elinvoimaisuutta selvitettiin arvioimalla latvuksien harsuuntuneisuutta ja laskemalla neulasvuosikertojen määriä. Lisäksi tutkittiin latvuksien värivikoja, käpysatoa sekä bioottisia ja ei-bioottisia tuhoja. Käytetyt tunnukset kuvaavat puiden yleistä elinvoimaisuutta eivätkä ne ole spesifejä ilman epäpuhtauksien vaikutuksille. Typpilaskeumaa kuvaavana bioindikaattorina pidettiin viherlevän kasvua neulasten pinnalla. Tutkimuksessa on käytetty korrelatiivista lähestymistapaa analysoitaessa harsuuntuneisuuden alueellisuuteen ja viiden vuoden harsuuntumismuutokseen vaikuttavia tekijöitä. Silmävaraisten arviointien luotettavuutta tutkittiin maastotesteillä.

Suomen havupuiden harsuuntuminen oli samalla tasolla kuin Ruotsissa ja Norjassa. Yli 20 % harsuuntuneita mäntyjä oli 11 %, kuusia 42 % ja lehtipuita 16 %. Keskimääräinen puukohtainen neulas- tai lehtikato oli männyllä 9 %, kuusella 21 % ja lehtipuilla 12 %. Edelliseen vuoteen verrattuna kuusen harsuuntuminen pysyi ennallaan, mutta männyn ja lehtipuiden lievästi vähentyi tarkasteltaessa koko maata koskevia frekvenssijakaumia. Koko viisivuotisen tutkimusjakson aikana harsuuntuminen lisääntyi 5 %-yksikköä männyllä, 16 %-yksikköä kuusella ja 7 %-yksikköä lehtipuilla. Kuusella harsuuntuminen oli pääasiassa "ikkunatyyppistä" (73 %), männyllä puolestaan oksittainen (41 %) ja tasainen harsuuntuminen (37 %) olivat vallitsevia. Neulasvuosikertojen määrässä ei ole ollut suurta vaihtelua vuosina 1986–1990.

Molemmilla havupuilla metsikön iän ja koealojen keskimääräisen harsuuntumisasteen välillä oli erittäin merkitsevä positiivinen korrelaatio. Etelä-Suomen mäntyaineistosta löydettiin merkitsevä positiivinen korrelaatio mallitetun rikkilaskeuman ja koealojen keskimääräisen harsuuntumisasteen kanssa (Spearmanin järjestyskorrelaatio $r_s = 0.226$, $p < 0.01$, $n = 194$), rikkilaskeuma korreloi tällä alueella lievästi myös männyn viiden vuoden harsuuntumismuutoksen kanssa ($r_s = 0.197$, $p < 0.01$, $n = 187$). Sekä männyllä että kuusella löydettiin suuntaa-antava positiivinen korrelaatio rikkilaskeuman ja keskimääräisen harsuuntumisasteen välillä alle 65-vuotiaiden metsien koko Suomea koskevassa ositteessa (mänty: $r_s = 0.158$, $n = 136$; kuusi: $r_s = 0.186$, $n = 98$, molemmat $p < 0.100$).

Neulasten värioireita havaittiin joka kolmannella männyllä ja joka toisella kuusella, mutta värioireiden aste oli 85 % :ssa tapauksista hyvin lievä (alle 10 % latvuksen neulasista oireellisia). UN-ECE -ohjeistossa tämän asteinen värivikaisuus koodataan oireettomaksi. Oksien yläpinnan haalistumista tavattiin kolmanneksella tutkituista (n = 336) kuusista. Neulasten kloroottisuus ja keltakärkisyys olivat yleisempiä oksien yläpinnalla ja valolle altistuneissa oksissa, mikä saattaa johtua neulasten solukoiden valoherkkyydestä. Neulasten värioireiden kytkeytyminen esimerkiksi magnesiumin puutokseen, alailmakehän otsonipitoisuuteen tai säätekijöihin vaatii lisätutkimuksia.

Havupuiden käpysato vaihteli suuresti vuosien 1986 ja 1990 kuluessa. Harsuuntumisasteen ja käpyjen määrän välillä ei havaittu yhteisvaihtelua puukohtaisessa tarkastelussa. Sen sijaan käpysato kasvoi metsikön iän myötä. Erilaisia tuhoja kirjattiin 56 %:lla havupuista. Mitä harsuuntuneempia puut olivat sen useammin ja sitä vakavampia tuhoja niillä ilmeni. Akuuttia versosurmaa tavattiin 4 %:lla vallitsevan latvuskerroksen männyistä.

Kolmasosalla tarkistetuista kuusista (n = 533) havaittiin leväpeitettä neulasten pinnalla. Useimmin levää oli pohjoisen puoleisissa oksissa, missä kosteampi pienilmasto suosii levän kasvua. Nuorissa alle 40-vuotiaissa metsissä ja lehtomaisilla kankailla oli suhteellisesti enemmän viherleväisiä kuusia kuin vanhemmissa metsissä tai karuimmilla kasvupaikoilla. Suomessa levää esiintyy Oulun korkeudelle saakka. Sekä Suomessa että Ruotsissa levän esiintymisalueella typpilaskeuma on yli 6 kg/ha vuodessa. Metsäekosysteemin kriittinen raja typen suhteen vaihtelee eri kasvupaikoilla, havumetsissä rajaksi on arvioitu 3–15 kg/ha vuodessa.

Harsuuntumiseen vaikuttavat tekijät kytkeytyvät voimakkaasti toisiinsa, mikä vaikeuttaa syy-seuraus - suhteiden analysointia. Harsuutumista selittävät tekijät vaihtelevat maantieteellisen sijainnin, puiden kehitysvaiheen, herkkyyden ja ympäristön saastuneisuuden mukaan. Viiden vuoden seurannan perusteella vaikuttaa siltä, että metsäpuiden harsuuntumista tausta-alueilla selittävät Suomessa pääasiassa luontaiset tekijät kuten metsien korkea ikä ja erilaiset sää- ja ilmastotekijät. Versosurmaepidemia on lisännyt mäntyjen harsuuntumista maan länsiosissa. Ilman epäpuhtauksilla on ollut ilmeisesti vaikutusta harsuuntumisen lisääntymiseen Etelä-Suomen kuormitetuimmissa osissa. Täällä harsuuntuminen on lisääntynyt viiden vuoden aikana myös nuorissa metsissä. Ilman epäpuhtauksien alhaisetkin pitkäaikaiset pitoisuudet saattavat vaikuttaa haitallisesti puiden terveydentilaan pohjoisen kylmässä ilmastossa.