FOREST CONDITION IN FINLAND 1986–1990

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Annual report of forest condition in Finland 1990

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Summary

During a five year period, 1986–90, the state of health of the same 3,850 trees on 450 permanent, systematically sampled mineral soil plots was surveyed. The vitality of trees was investigated by estimating the defoliation degree and counting the number of needle age classes. In addition, discoloration symptoms of the crown and damages caused by abiotic and biotic factors were investigated. The used variables were general vitality indicators and they were not specific to air pollutants. The reliability of the visual vitality estimates was examined. The growth of green algae on the needles was used as a bioindicator of the state of the environment. The dense algal growth indicates especially nitrogen deposition.

According to the five–year monitoring one can conclude that defoliation of forest trees is mostly explained in Finland by natural factors such as ageing of the stands and different weather and climatic conditions. Air pollutants are obviously playing a role in the increase of defoliation in the most polluted part of southern Finland. In this area defoliation has increased during the 5–year period also in young stands.

1. Introduction

A considerable effort in developing the international environmental statistics and databases has been made during the past 10 years in consequence of the increasing concern over ecological problems. Knowledge of the state of the environment is needed for the international conventions which aim to reduce the nitrogen and sulphur emissions and to limit the use of chlorofluorocarbons (CFCs). Reliable and representative ecological data is also needed to realise sustainable economic development and to elaborate an index of green GDP (Gross Domestic Product).

The Finnish Forest Research Institute is the national Focal Centre which produces the forest information in Finland. From 1985 Finland has taken part in the UN–ECE program in the forest damage survey. The UN–ECE–report publishes the statistics of the state of health in forests of about 30 European countries. The methods used for vitality assessment in these surveys are visual defoliation and discoloration estimations. The first results from Finland were given out in 1985–86 (Jukola–Sulonen et al. 1987). From there on the annual Finnish results have been published in the ECE statistics (Anon. 1987, 1988a, 1989a, 1990a). A more complete analysis of the vitality of the Finnish conifers in 1986–88 was published in the final report of the Finnish Acidification Research Programme (HAPRO) (Jukola–Sulonen et al. 1990).

In this paper the Finnish results from the extensive level survey in 1990 are presented. The aim of this project is to monitor and survey the vitality of forests vegetation at national level, and to determine the extent to which air pollution can explain any recorded damage.

2. Material and methods

2.1. Forest area in Finland

Forests cover 26.4 million ha, of which 20.1 million ha are productive forest (annual growth over 1.0 m^3/year/ha). Conifer forests cover 18.5 million ha, roughly two thirds of which is Scots pine (*Pinus sylvestris* L.) and one third Norway spruce (*Picea abies* (L.) Karst.). Broadleaved forests (1.6 million ha) consist mainly of *Betula* spp. (1.4 million ha) and others, mainly *Populus tremula* L. and *Alnus* spp. (0.2 million ha) (Anon. 1989b).

2.2. Hierarchical survey design in Finland

Temporary sample plots

The forest damage survey is part of the national forest inventory (NFI) comprising 80,000 systematically distributed, temporary sample plots. 11,000 of these are damage inventory plots (about 35,000 trees), on which defoliation is assessed. The 8th National Forest Inventory was started in 1986 and should be completed by 1995. The normal inventory cycle is 8–9 years. Regional defoliation results (from different parts of Finland) are available at regular intervals (Anon. 1990b, Nöjd 1990). In the near future the national forest inventory will be converted into a permanent sample plot system (50,000 plots). The new system differs from the current one in that growth and defoliation data, will be available for the whole country on an annual basis.

Permanent sample plots

Systematically distributed, permanent sample plots (3,009) covering the whole country were established in 1985–1986 in connection with the 8th National Forest Inventory. The country is divided into a northern and a southern region. A lower sampling density is used in the northern region. 391 sample plots are located in the north and 2,618 in the south. The sampling units in the north are 3–plot clusters arranged in a 32 x 24 km grid, and in the south 4–plot clusters in a 16 x 16 km grid. Marking of the permanent sample plots were hidden so that it does not affect forest management. The monitoring in this network is done at 5–year intervals.

The condition, chemistry and structure of the forest ecosystem on the permanent plots were studied during 1985–86. Special attention was paid to trees (5,400 conifers), epiphytic lichens (Kuusinen et al. 1990, Kubin 1990) and the ground vegetation (Tonteri 1990, Tonteri et al. 1990). Tree vitality was studied only in conifers by estimating defoliation, number of needle age classes, and crown discoloration (Jukola–Sulonen et al. 1987). Tree dimensions were measured and the distribution and intensity of natural damaging agents surveyed (Nevalainen & Yli–Kojola 1990). These plots will be resurveyed in 1990–91.

Annual surveys in 1986–1990

Altogether 450 mineral soil plots situated on mineral soil are assessed each year, 1986–1990 (Fig. 1.). 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 circle shaped plot was 300 m^2. All trees at least 4,5 cm diameter at breast height in dominating crown layer were estimated. In 1990 there were 3,437 conifers and 413 broadleaves alive. Owing to methodological differences, these annual results are not comparable with the results of the full survey networks.

2.3. Vitality variables in annual surveys

The tree vitality variables used in 1990 can be classified into the three groups: (A) characters depicting the amount and variation of the phytomass, (B) needle and leaf discoloration, (C) abiotic and biotic damages (Table 1). All variables were estimated using binoculars. Detailed visual needle analysis was performed on permanent sample branch from the lower crown. Each year the same four observers assessed the same trees using unchangeable methods. The survey was carried out in July–October in 1990. Discoloration in all tree species and defoliation in broadleaves were not estimated after August when the normal phenological events change the colour of the crowns and when shedding of the leaves begins.

Defoliation was recorded in 10 % classes for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), birch (*Betula* spp.), aspen (*Populus tremula*) and alder (*Alnus* spp.). 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 crown. Details of the assessment procedure are given in Jukola–Sulonen et al. 1990.

The number of needle age classes of conifers was estimated on the upper part of the crown for pine, and on the lower part of the crown for spruce.

Needle discoloration was estimated on the same part of the crown as defoliation. Needle tip yellowing, yellowing and browning were recorded in two needle age classes; the current year's needles (born in 1990) and the older needle generations (born before 1990). Codes are given in Table 1. Sample branches for detailed analysis of needle discoloration and green algae were selected in the trees having accessible branches in the lower crown. The direction of the sample branch was determined using compass. Exposure of the branch to light was also estimated.

The ordinary abiotic damages (e.g. climatic and anthropogenic), and biotic damages caused by pathogens and herbivores were estimated.

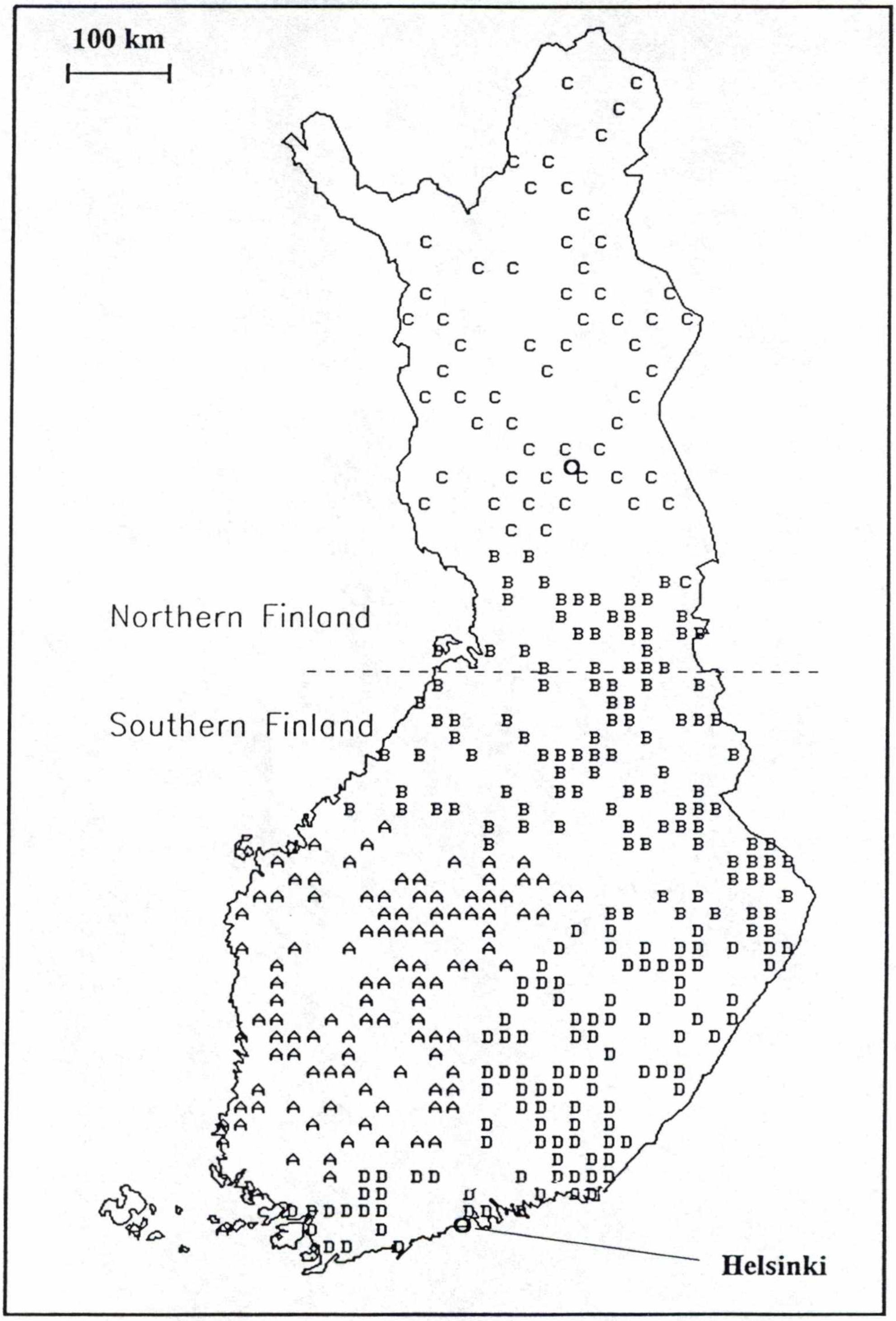


Figure 1. Location of the sample plots (n=450). The letters A–D refer to the areas surveyed by the four observers.

Table 1. Variables used in monitoring the Finnish forest condition in 1990.
Both conifers and broadleaves were studied.

A) Amount and variation in the phytomass

1. Defoliation

Estimated in 10 % needle/leaf loss classes:

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

2. Needle age classes (years)

Estimated from the upper and lower crown of pine and from the lower crown of spruce.
In both species measured from the permanent sample branch in the subsample.

B) Needle and leaf discoloration

3. Needle tip yellowing in the current year's needles and in the older needle generations
4. Needle yellowing in the current year's needles and in the older needle generations
5. Needle browning in the current year's needles and in the older needle generations

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

C) Abiotic and biotic damages

6. 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

7. Abundance of the fungal pathogen *Ascocalyx abietina* (assessment when moving 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

Variables of the sample branch

8. Colour difference between the upper and the lower sides of the branch
   Codes: 1 = normal, upper side darker 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

9. The type of the previous colour defect
   Codes: 1 = needle tip yellowing (>1/2 mm in the tip)
   2 = needle chlorosis
   3 = light or yellow flacks/mottling in the upper side of the needles
   4 = upper side of the needles brownish green or having brown flacks
   5 = tip yellowing with chlorosis
   6 = tip yellowing with flaking

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

11. Green algae on the needle surface
    Codes: 0 = no algae growth
    1 = scanty algal growth
    2 = abundant "

3. Reliability of the results

The main problem of the visual methods is the reliability of the results (Innes 1988, Innes & Boswell 1990, Jukola-Sulonen et al. 1990). Despite training, defoliation and discoloration estimations of standing trees are always subjective and consist of error variation. There may be bias in the determinations of the number of needle age classes, too. This may partly be due to the fact that different observers study different branches of the same tree which has within-crown variation in the number of needle age classes. Stand density, weather and illumination all affect the estimation.

It is important that individual estimation level remains consistent throughout the monitoring. In this study the same four observers estimated the same trees every year, which improves the compatibility between different years. Before the field work the observers had a weeks' training course.

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 after the field period. The four observers estimated independently the defoliation, discoloration and the number of needle age classes on pines and spruces.

The consistency in defoliation estimations was better for pine than for spruce in 1990. On the average, 65 % of the pines and 41 % of the spruces were estimated identically by the different observers. Within an error margin of one class (1 class over or underestimates) 92 % of the pines and 75 % of the spruces were estimated consistently (Fig. 2). There was a small systematic error in the results of observer A, whose area was in western Finland. This systematic error was expressed as observer A's higher defoliation estimations for both pine and spruce. The effect of correction of this level difference was studied as follows. Half of the trees classified into a particular defoliation class were dropped one class lower in each sample plot in western Finland. The trees for correction were randomly selected. The correction minimized the differences in defoliation between western and eastern Finland but the main regionality remained unchanged. Because the correction had a very small effect on the defoliation distributions of the whole country level the results presented in this paper are without correction.

The estimation of the number of needle age classes was more reliable than 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) (Table 2). In contrast, discoloration estimations still need to be improved. Owing to differences between observers only discoloration distributions of the whole country are presented in this paper.

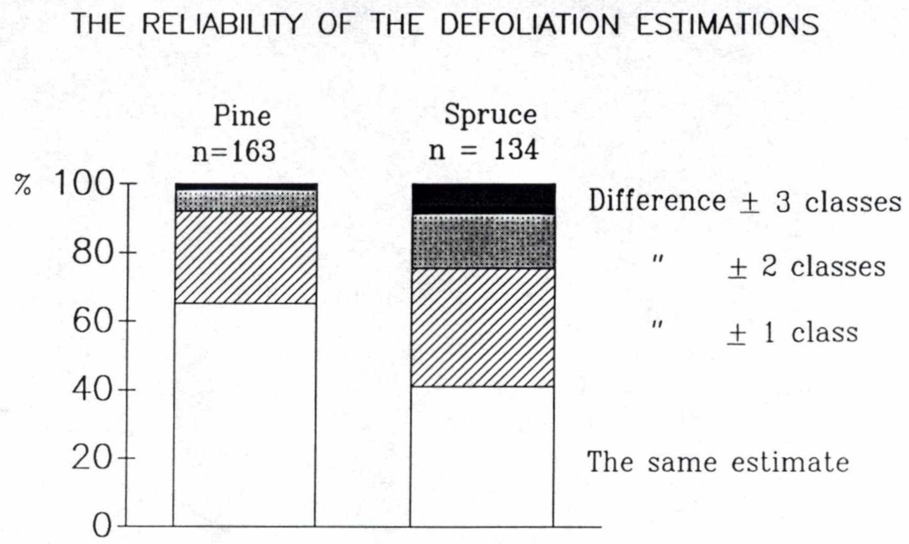


Figure 2. The reliability of the tree-specific defoliation estimations in pine and spruce. The diagram depicts how many cases the personal estimations were exactly the same and how often deviation in judgement was 1 class, etc.

Table 2. The consistency in the number of needle age classes (x ± sd) determined by the four observers (A–D) in the field test. No differences were found between the observers (one way ANOVA statistics included).

Pine (upper crown), n = 157

Observer	x	sd
A	3.7	0.8
B	3.8	0.8
C	3.8	0.8
D	3.9	0.7

One way ANOVA:

$F_{3,627} = 1.91$, P=0.12

Spruce (lower crown), n = 37

Observer	x	sd
A	8.1	1.7
B	8.5	1.9
C	8.4	1.9
D	8.4	1.9

One way ANOVA:

$F_{3,147} = 0.28$, P=0.84

4. Results

4.1 Defoliation

The whole country

The condition of 4,000 conifers and broadleaves were monitored during the five years, 1986–90. Altogether 7 % of the trees were lost during this study period, 1.5 % were dead and 5.6% had been cut. Defoliation frequency distributions were strongly skewed in all years. The majority of the trees were classified into the low defoliation classes (Table 3). According to the Nordic view defoliation up to 20 % is regarded as normal variation in the phytomass. The proportion of the 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 proportion of the sample plots in which all trees were below the 20 % needle loss limit was 32 % in pine (Fig. 5) and 14 % in spruce (Fig. 7).

Defoliation had increased in all tree species by 9 % units during the five years. The increase was 5 % units in pine, 16 % units in spruce and 7 % units in broadleaves (Table 2). Defoliation increased every year except the last year (1990) when the situation remained unchanged or a slight recovery was observed.

The proportion of the defoliated trees was the higher, the older the stand was. Defoliation was more common in stands older than 60 years. Also, the degree of defoliation was higher in these stands (Fig. 3). Defoliation increased in young pine forests during the first three and in young spruce forests during the first four years.

Regionality

Regionality of the defoliation is depicted in three ways:

(1) Regional averages. The means for needle loss classes were calculated from the midpoint classes (class 0 = 5%, 1 = 15% etc.). The size of the grid was 50 x 50 km^2. The grid consisted of 1 to 15 sample plots and at least four trees. This approach may be too general because of the small number of trees in particular areas.

(2) Regional pattern of sample plots having different frequencies of over 20 % defoliated trees.

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

According to grid averages defoliation in pine was strongest in Lapland and in some areas in southern Finland, too (Fig. 4). Sample plots in which most trees exeeded the 20 % defoliation limit were situated,

Table 3. Defoliation frequency distributions of the same trees during 1986–90 in the whole country.

	Years	n	DEFOLIATION PERCENTAGE 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

Table 4. The number of needle age classes (minimum, maximum and x ± sd) of pine (n=1863) and spruce (n=601) in the whole country.

Pine (upper crown):

Year	Min	Max	Mean	Sd
1990	2	9	4.0	0.8
1989	1	7	3.9	0.8
1988	2	6	3.8	0.7
1987	1	7	3.7	0.7
1986	2	7	3.8	0.7

Spruce (lower crown):

Year	Min	Max	Mean	Sd
1990	3	18	8.0	1.9
1989	4	19	7.5	1.8
1988	3	15	7.5	1.9
1987	3	14	7.6	2.0
1986	1	15	7.8	2.2

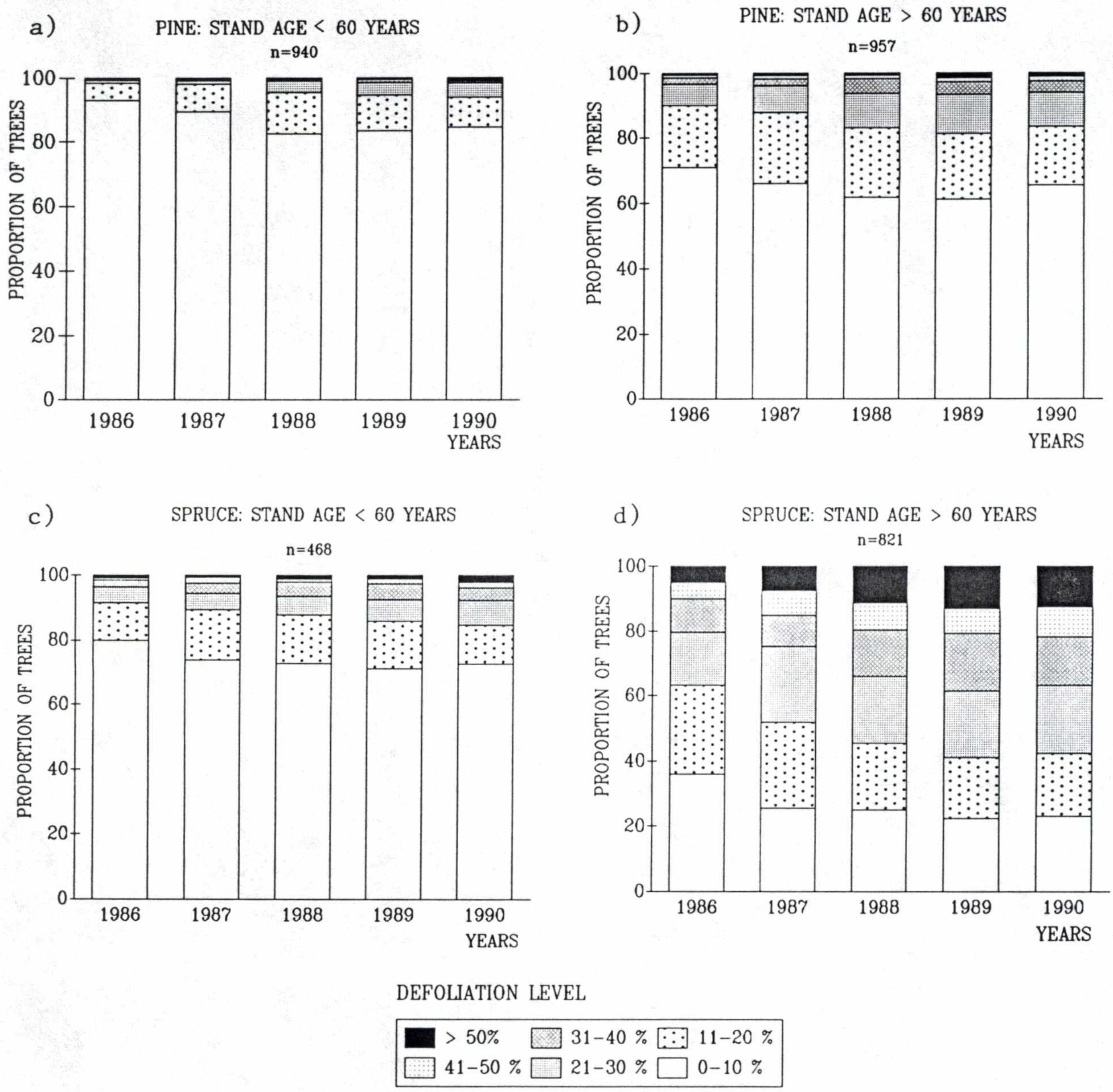


Figure 3 a–d. Defoliation frequency distributions of conifers by 10 per cent needle loss classes during 1986–1990. The results are given in the two age classes of the stands.

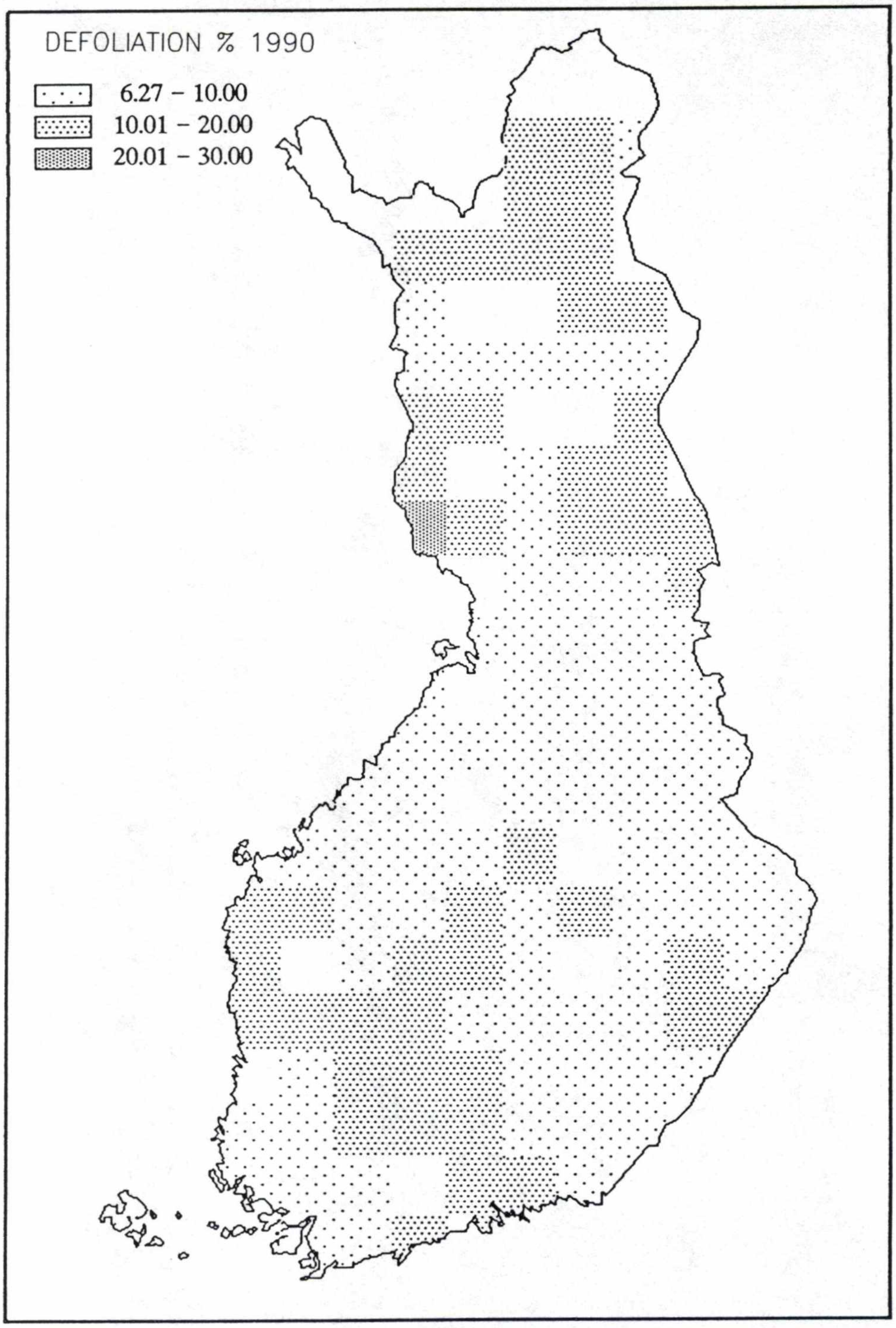


Figure 4. Defoliation of pine in 1990. 50 x 50 km^2 grid averages are given. One grid consists of 1 to 15 sample plots and at least four pines. White areas lack data.

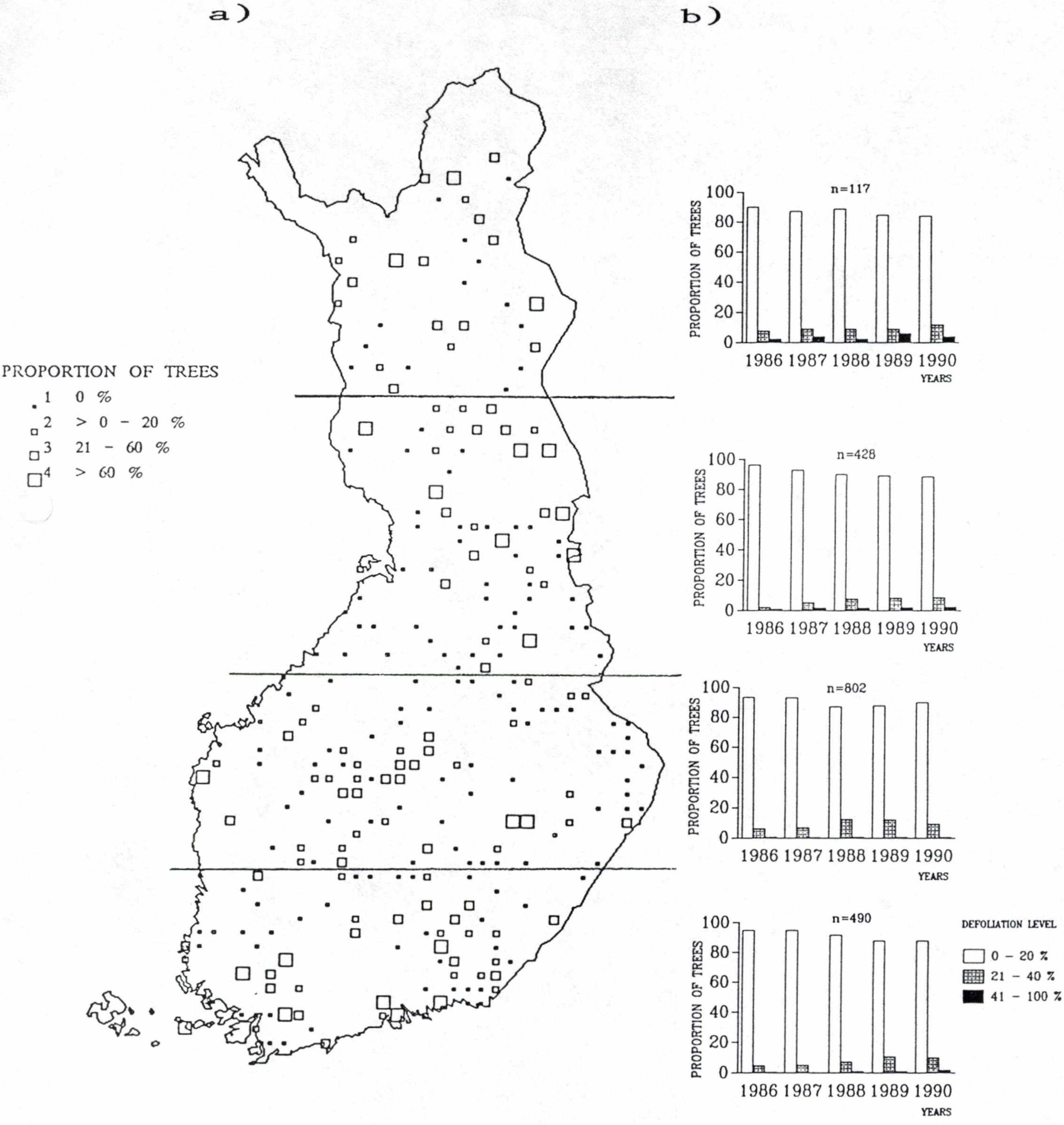


Figure 5. a) Defoliation of pine in 1990 as the pattern of sample plots having different proportions defoliated trees. The size of the square indicates the frequency of the trees defoliated > 20 % in each plot.
b) Defoliation distributions in pine during 1986–90 in the four latitudinal zones. The light column depicts the proportion of pines showing 0–20 %, dark column 21–40 % and black column > 40 % needle loss.

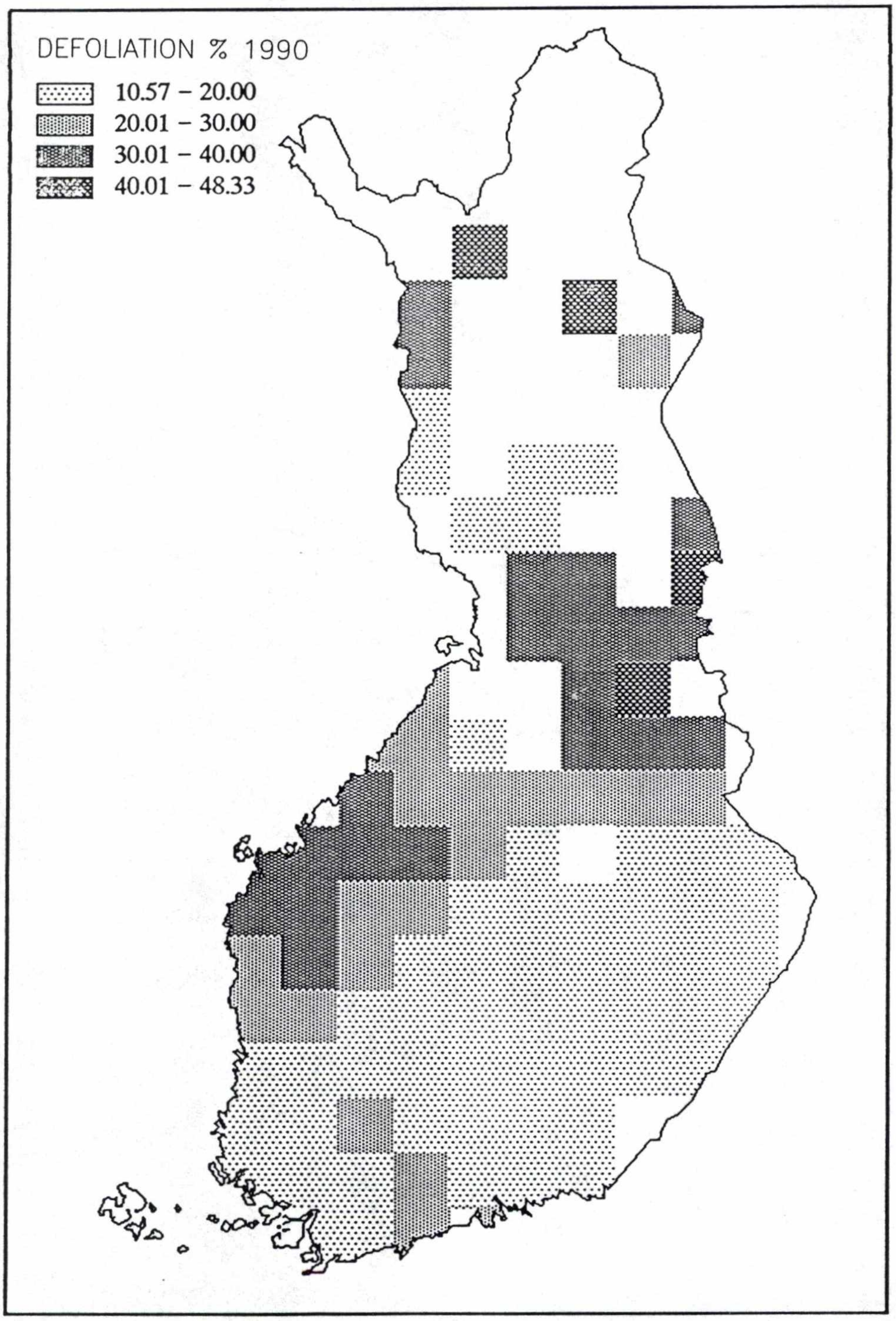


Figure 6. Defoliation of spruce in 1990. See explanations in Fig. 4.

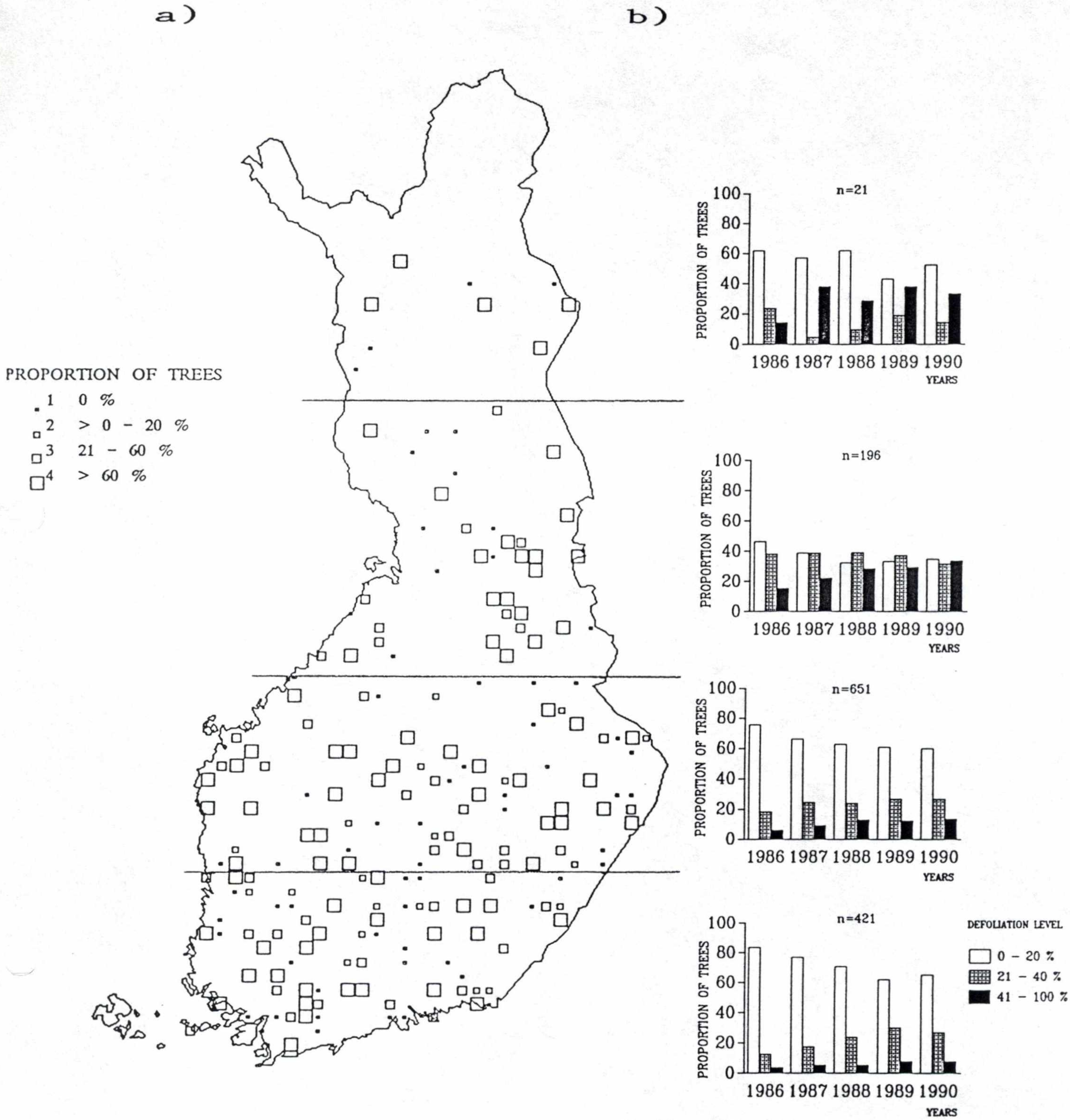


Figure 7. a) Defoliation of spruce in 1990 as the pattern of sample plots having different proportions defoliated trees. See details in Fig. 5a.
b) Defoliation distributions in spruce during 1986–90 in the four latitudinal zones. See column explanations in Fig. 5b.

besides Lapland, in SE and SW Finland and in some areas in Central Finland (Fig. 5a). Defoliation in pine was most severe in 1987 in Lapland (zone 4) and in 1988 in the central parts of the country (zone 2) (Fig. 5b).

The most defoliated spruces were located in Lapland, Kainuu and Ostrobothnia according to grid averages (Fig. 6). On the contrary the proportion of spruces that exeeded the 20 % defoliation limit was high in almost all sample plots (Fig. 7a). When comparing the four latitudinal zones it is evident that defoliation was clearly most severe in all the monitoring years in Kainuu and Lapland (zones 3 and 4) (Fig. 7b).

Changes

Defoliation in pine decreased or remained unchanged in the whole country except southern Lapland and Uusimaa in the last study period 1989–90 (Fig. 8a). In these areas defoliation increased. Defoliation in spruce increased by 2–5 % units of grid averages in Kainuu and southern Ostrobothnia during 1989–90, while no change or slight recovery was observed in the other parts of Finland (Fig. 8b).

Increase in defoliation of pine during the 5-year period was detected in two regions: South Lapland and southern Finland (Fig. 9a). Defoliation decreased or remained unchanged elsewhere. In young, under 60-years-old forests defoliation increased in central parts of Finland (Fig. 9b).

Defoliation in spruce increased in the greatest part of the country, mostly in Kainuu, southern Ostrobothnia and southern coast (increase was 7–20 % units in grid averages) (Fig. 10a). In young under 60-year-old spruce forests defoliation increased in the southern half of the country (Fig. 10b).

4.2. Needle age classes

The number of needle age classes varies naturally between northern and southern part of the country. The average number of the needle age classes on pine was 3–4 in southern, 3–5 in central and 4–5 in northern Finland. The corresponding values on spruce were 6–7, 7–9 and 10–11 (Figs. 11 and 12). Table 4 shows the average number of needle age classes in the pooled data of the whole country. This make it possible to compare how synchronised the changes in defoliation (Table 3) and in needle age classes (Table 4) are on the whole country level.

There was very little variation in the number of needle age classes in the different years within the each geographical area. The largest differences were about a half of age class. The number of needle age classes was slightly higher in the summer 1990 than in the previous year. Pine had the lowest number of needle age classes in Lapland in 1987 and in Ostrobothnia in 1988. The lowest numbers for spruce occurred in 1986 in SE Finland and in 1989 in central parts of the country (Figs. 11 and 12).

a)

b)

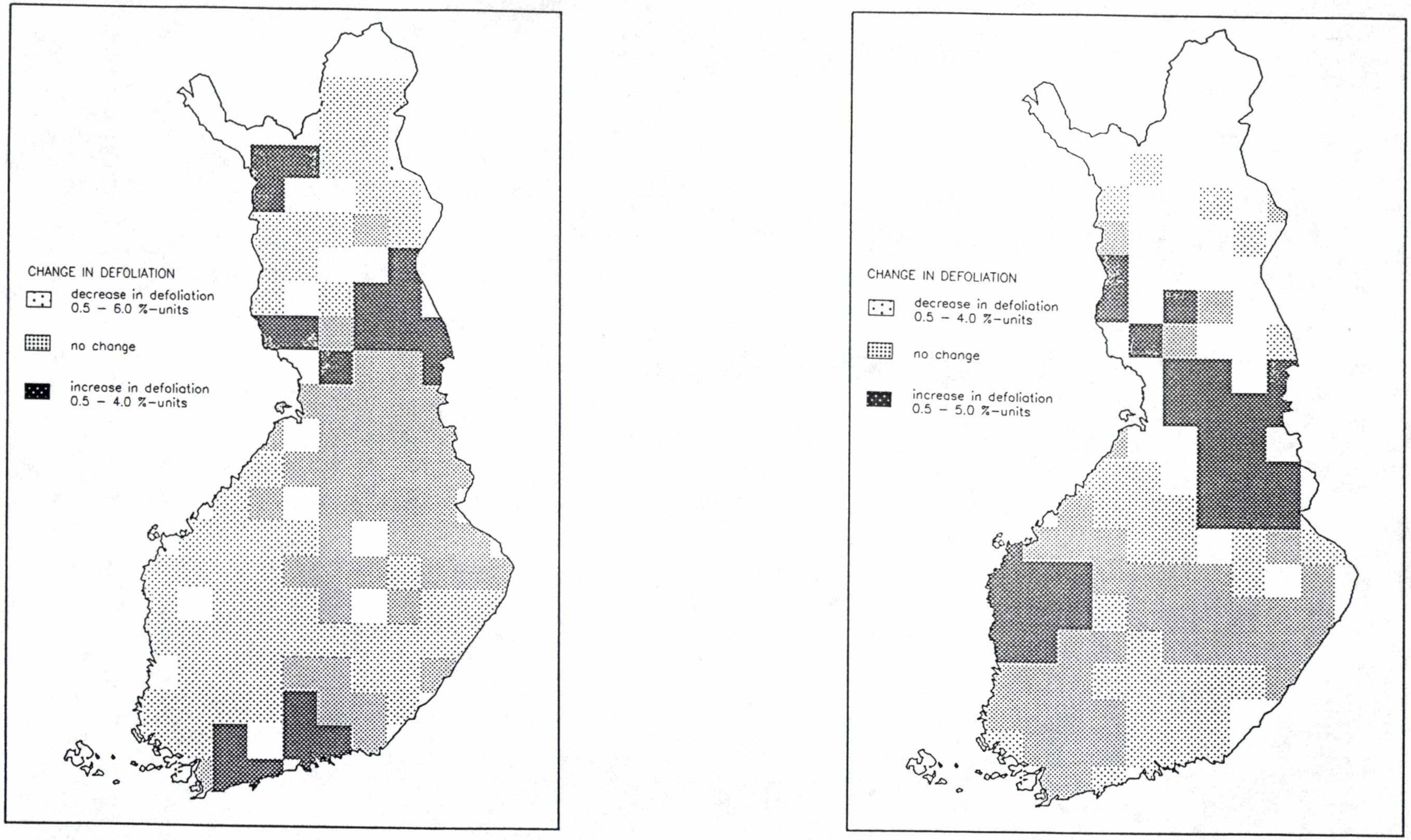


Figure 8. Change in the defoliation for a) pine and b) spruce during 1989–90. Averages for 50 x 50 km^2 grids are given. No observations in white areas. Defoliation was decreased in light areas, remained unchanged in grey areas and slightly increased in dark areas.

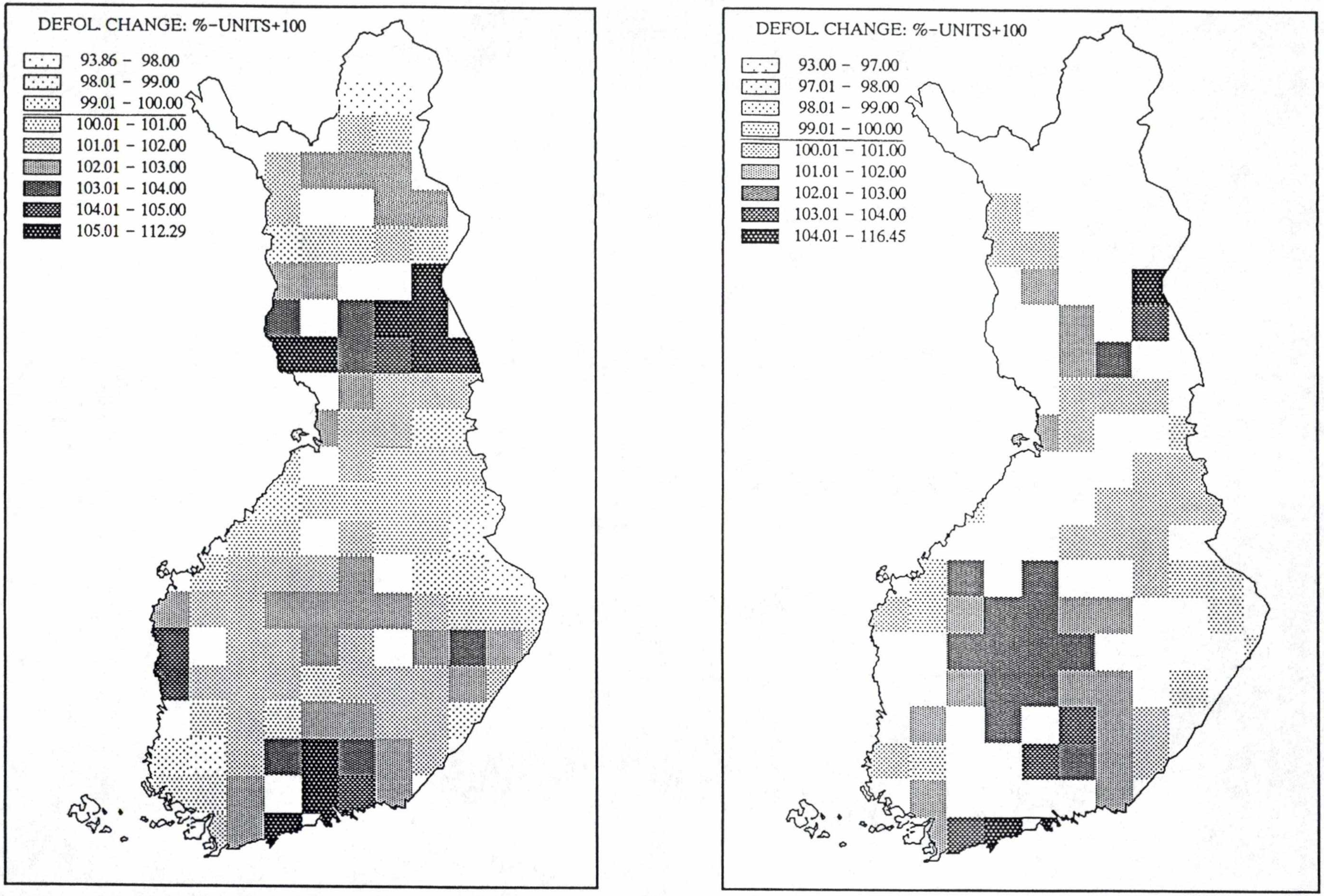


Figure 9. Change in defoliation for pine between the year 1986 and 1990 a) in stands of all ages, b) in young stands (<60-year-old). Legend: rasters above the line indicate decrease in defoliation and under the line increase in defoliation.

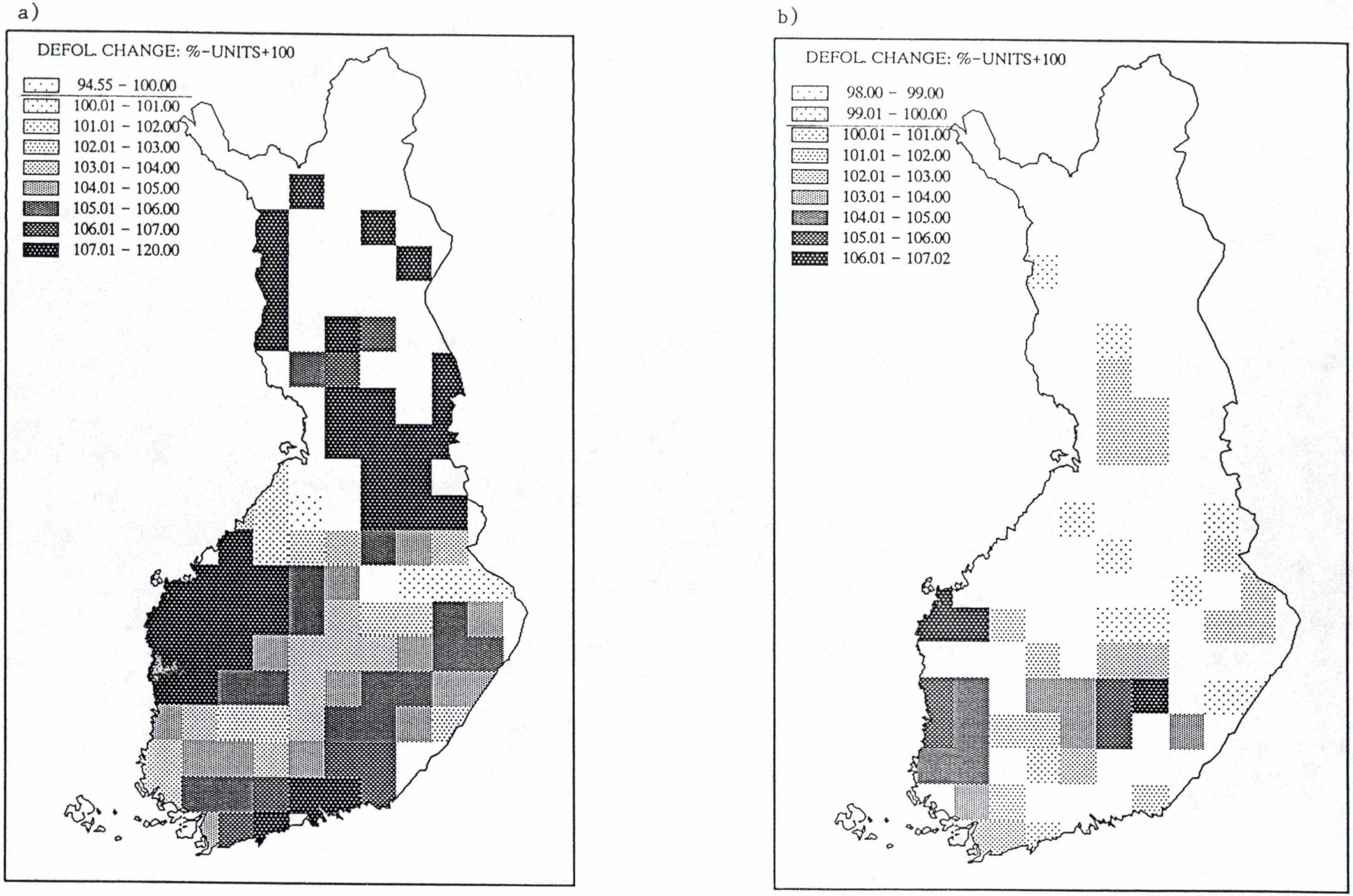


Figure 10. Change in defoliation for spruce between the year 1986 and 1990 a) in stands of all ages, b) in young stands (<60-years-old). See explanations in Fig. 9.

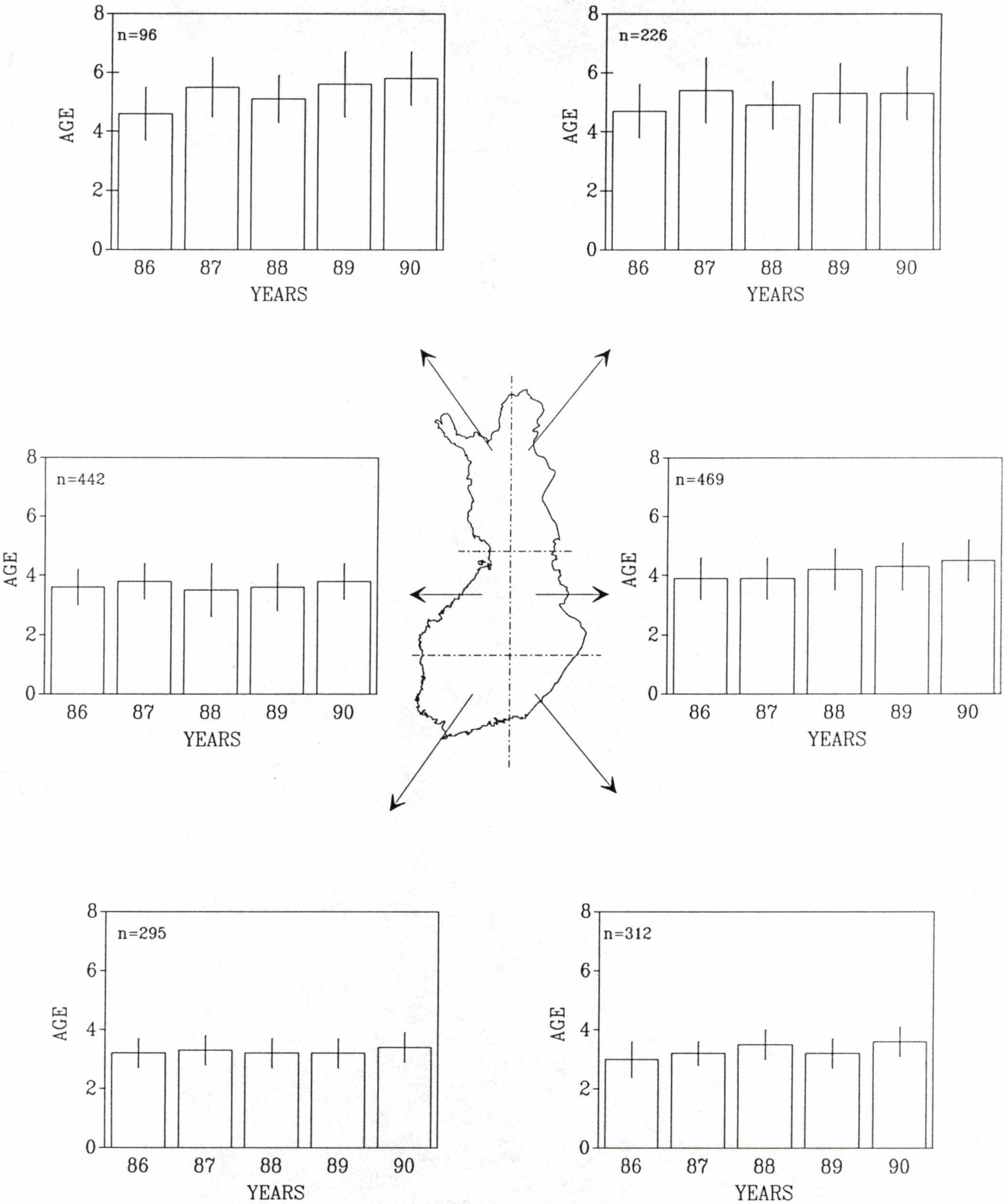


Figure 11. The number of needle age classes for pine (x ± sd) during 1986–1990 in different parts of the country. A needle age class was equal to an annual shoot with at least half of the needles still attached.

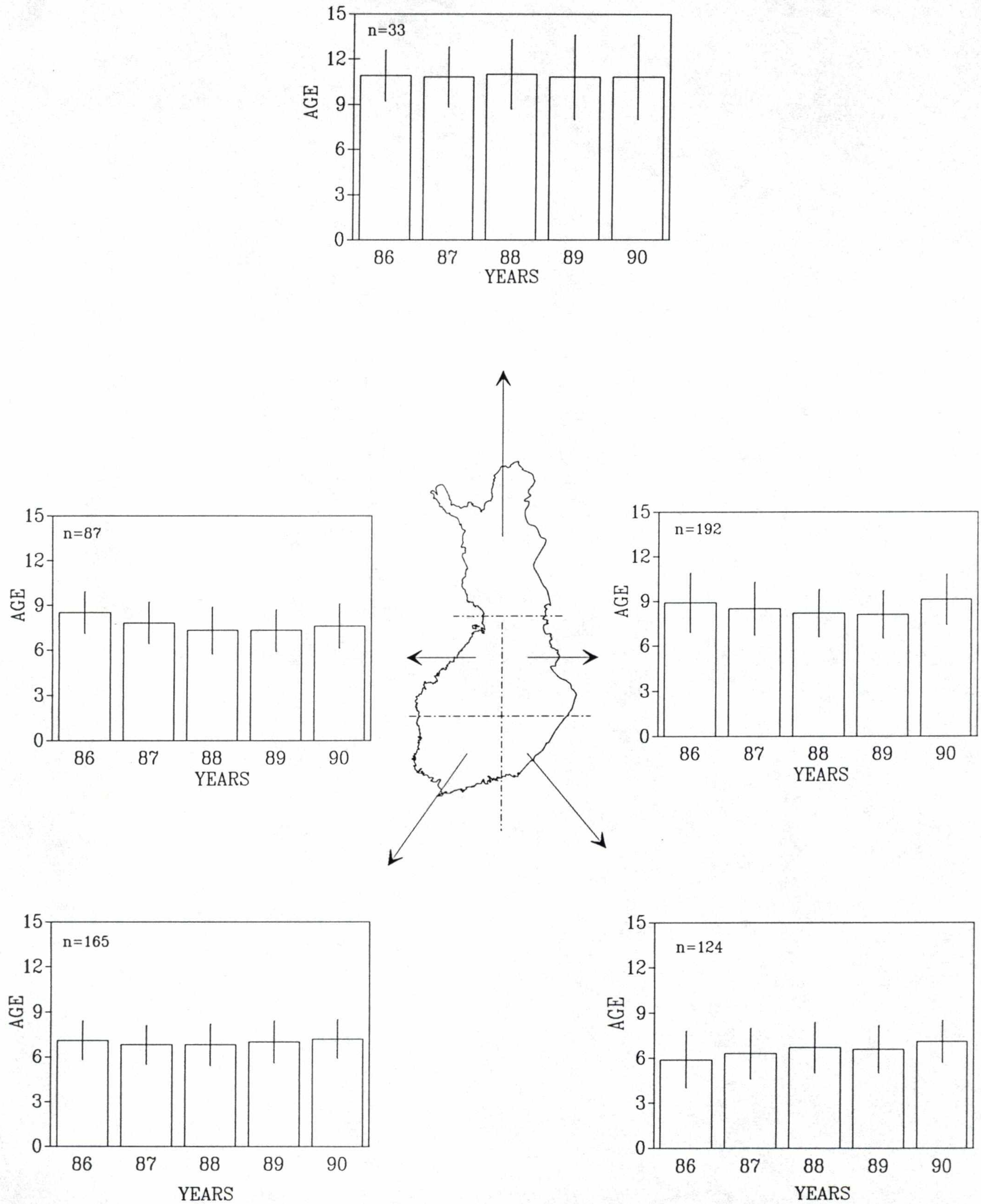


Figure 12. The number of needle age classes for spruce (x ± sd) during 1986–1990 in different parts of the country. See details in Fig. 11.

4.3. Discoloration

Crown discoloration

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

Pine: The older needles' tip yellowing was recorded in 4 %, yellowing in 21 % and browning in 13 % of the pines. Under 10 % of the needles were affected in 90 % of the cases. In the ECE Manual (Anon 1988b) discoloration of this degree is coded as 'none'. Defoliated pines had more frequently needle discoloration than none–defoliated pines. Needle tip yellowing was most common on poor sites. Needle yellowing was recorded evenly on the all sites but needle browning was observed most often on fresh sites and in rocky areas.

Spruce: Needle tip yellowing of the older needles was more frequent (40% of the spruces) than yellowing (24%) or browning (14%). As in pine, discoloration in spruce was more common in defoliated trees. Needle tip yellowing and yellowing were most frequent on fresh sites while needle browning was recorded most often on the most fertile sites.

Discoloration in sample branch

Blading of the upper surface of the sample branch was recorded on one third of the studied 336 spruces. Colour difference between the upper and lower sides of the branch was more frequent in the branches exposed to light than branches in the shadow (Fig. 13a) whereas compass direction of the branch did not affect blading. The colour difference was expressed as over two year old needles' chlorosis, also needle tip yellowing or flaking were recorded (Fig. 13b). Needle yellowing on the upper side of branches was observed locally throughout the country, especially in southern and central Finland. There was more often colour difference of the branch in trees growing on poor sites. On the other hand, increase in defoliation or stand age had no increasing effect on the frequency of the branch colour defect.

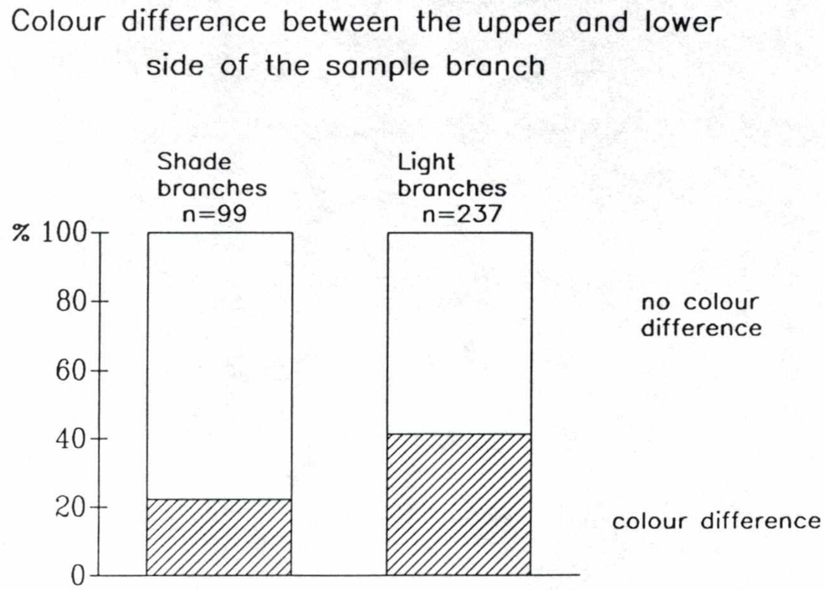
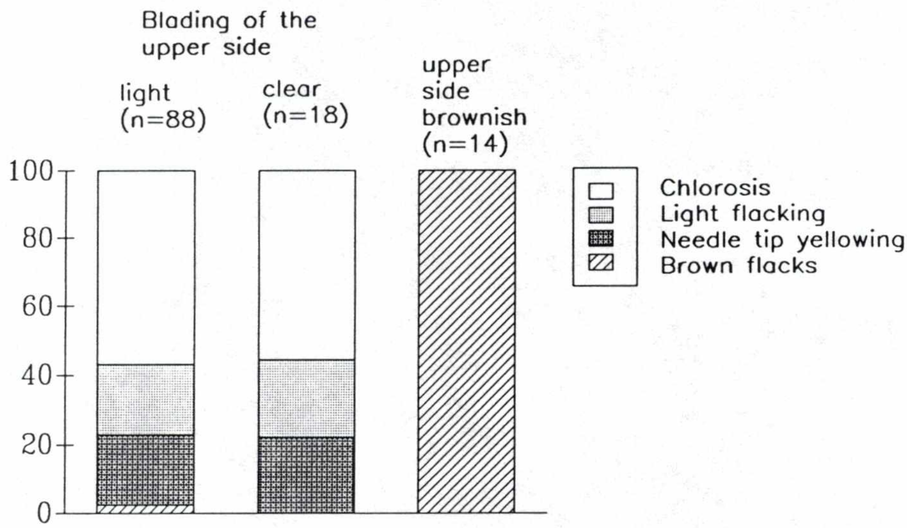


Figure 13. a) The frequency of the trees showing colour differences between the upper and lower sides of the sample branch. Branches exposed to light and branches in shade are treated separately. The difference between the two branch types is statistically significant (X^2=11.13, df=1, P=0.001).



b) The type of the discoloration in the sample branches having different degree of colour defect.

4.4. Abiotic and biotic damages

The proportion of trees with injury symptoms were 64.4 % on spruce and 49 % on pine. From all the trees with some damage symptoms the proportion of unidentified symptoms was 39.7 % on spruce and 14.1 on pine. The proportion of trees affected by damage agents increases as defoliation increases. Among the trees with defoliation higher than 40 %, only 1 % of the spruces and 8 % of the pines were unaffected (Table 5).

Pine canker (*Ascocalyx abietina*)

Pine canker has been a very serious problem in Scots pine forests in Finland during the past few years. The disease has ceased since 1989 but it still exists in certain areas (Fig. 15 a–c).

4.5. Green algae

Single–celled algae can react more rapidly to environmental changes than the more developed plants such as trees. Recently a large number of trees in southern and central Finland have been observed to have dense algal growth covering their needles. 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.

Altogether one third of the spruces (n = 533) studied in 1990 had green algae on the needles (Fig. 14). Most often algae were observed growing on branches facing north, presumably favoured by more humid micro–climate. The proportion of algae–infested spruces was higher in stands younger than 40 yr and in lush habitats as compared to older stands and more barren habitats. The northernmost limit of occurrence of the epiphytic green algae in Finland is at the level of Oulu. Nitrogen deposition in the growing range of the algae is >6 kg/ha both in Finland and in Sweden. Recalling that the estimated critical annual load for nitrogen in conifer forests, though varying greatly between habitats, is 3–15 kg/ha.

Table 5. Frequency of a) pines and b) spruces having abiotic and biotic damages at four defoliation levels. *Abiotic*: wind, snow, frost, etc., *Biotic*: fungi, insects and mammals, *Others*: competiton, ageing, harvesting, and other man–made injuries.

a)

PINE		PROPORTION OF TREES (%)				
DEFOLIATION %	NUMBER OF TREES IN DEF. CLASS	NO DAMAGE	NOT IDENTIFIED	ABIOTIC	BIOTIC	OTHER
0 – 20	1835	54.6	4.9	3.5	20.1	16.9
21 – 40	195	17.4	21.0	10.3	36.4	14.9
41 – 60	24	8.4	58.3	4.2	20.8	8.3
60 – 100	12	8.4	0.0	8.3	33.3	50.0

b)

SPRUCE		PROPORTION OF TREES (%)				
DEFOLIATION %	NUMBER OF TREES IN DEF. CLASS	NO DAMAGE	NOT IDENTIFIED	ABIOTIC	BIOTIC	OTHER
0 – 20	801	52.4	8.4	4.1	9.4	25.7
21 – 40	367	18.2	43.1	7.9	9.5	21.3
41 – 60	134	0.9	61.9	14.2	2.9	20.1
60 – 100	76	1.4	60.5	11.8	2.6	23.7

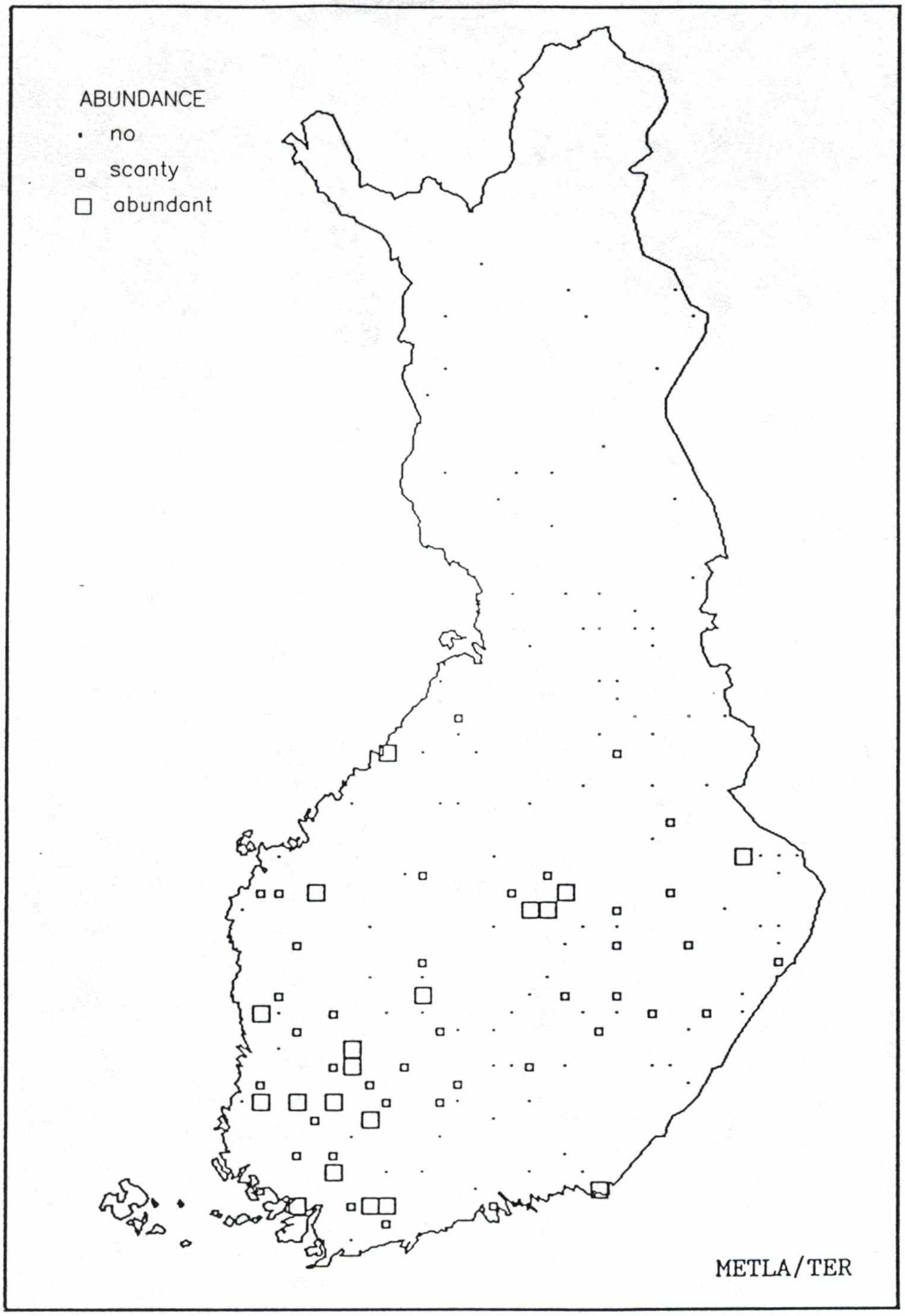


Figure 14. Regional pattern of the green algae growing on the needles of spruce. The size of the symbol indicates the abundance of the algae (mainly *Desmococcus olivaceus*).

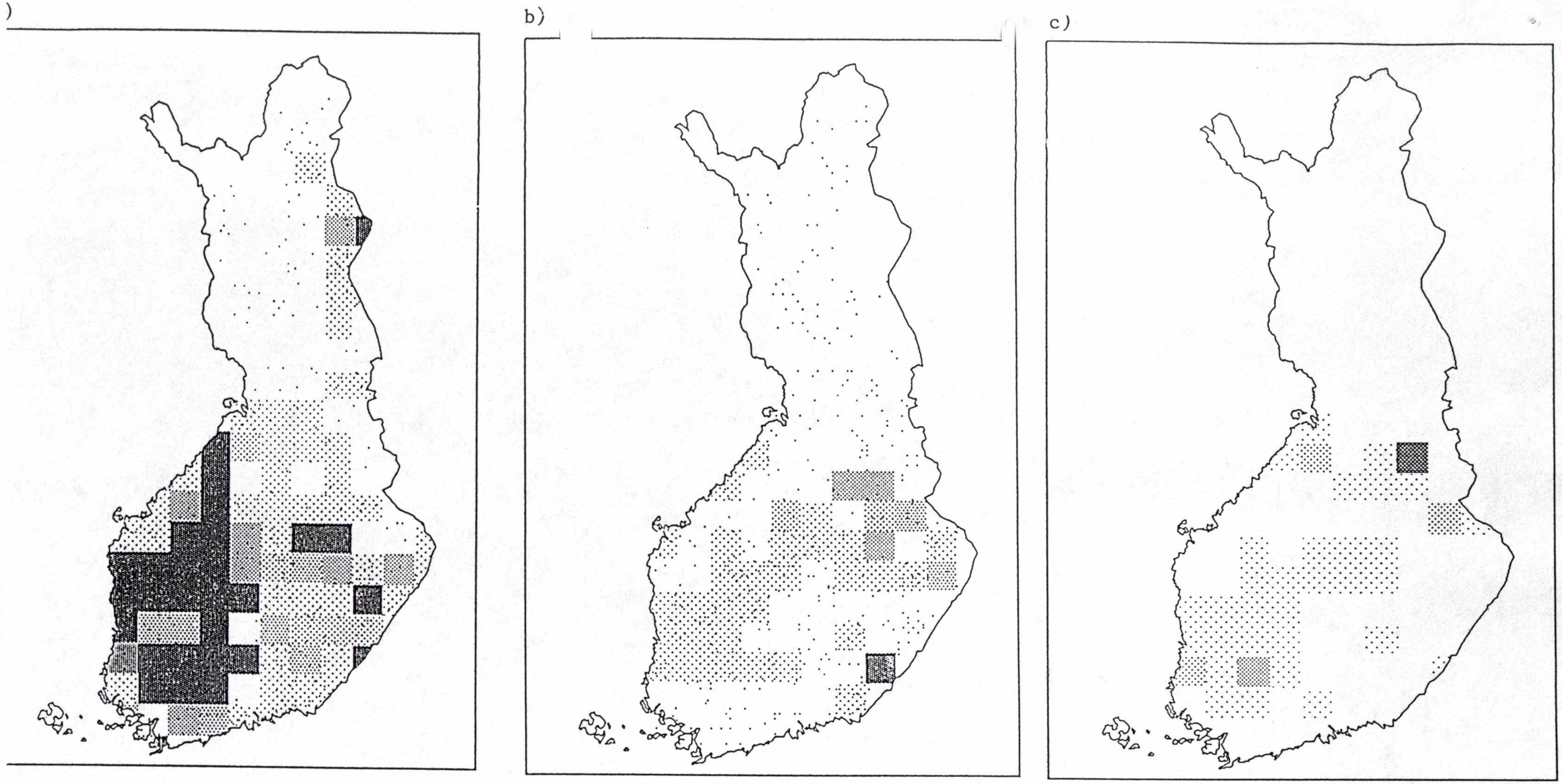


Figure 15a–c. Regional pattern of pine forests infected with pine canker, *Ascocalyx abietina*, during 1988–1990. The darker the raster the more severe the epidemic.

5. Discussion

5.1 Methodology

Several methods, from biochemical and cytological analyses to remote sensing, can be used to determine condition of forest trees. The relevance of methods used is dependent on the level of research intensity. General impression of tree vitality should be based on information collected by a variety of methods (Salemaa & Jukola–Sulonen 1990).

Extensive surveys of forest condition require methods easily applicable to large areas. The method should provide information that is comparable over different areas and times. For example, visual estimation of defoliation and discoloration has been used in assessing tree vitality in many European countries. The purpose of these inventories is to find out damage areas and to show clear changes in tree condition. Visual symptoms are restricted to current damages. However, they are less suited for prediction of vitality changes. For example, many biochemical and cytological changes precede crown discoloration and defoliation.

Defoliation, or needle or leaf loss, expresses the overall vitality and condition of trees. In addition to damage caused by biotic and climatic factors, air pollutants and other stress factors also affect the amount of and variation in needle biomass. The order of importance of such factors varies in each case depending on the degree of pollution, the geographical location, and the stage of development and sensitivity of the trees.

The variables characterising tree condition reflect both seasonal cycle and latitudinal gradient in Finland. In addition to this they are indicators of different anthropogenous stress factors. This means that annual changes in condition variables are presumably more informative measures of tree vitality than mere demonstrations of large–scale gradients.

5.2. Interpretation

Forest defoliation increased during the study period, and the greatest changes occurred in different areas in different years. The most defoliated forests were in Lapland, Kainuu and Ostrobothnia. High tree age and northerly location increased the degree of defoliation. No clear connections were found between the regional distribution of forest defoliation and the pollution load. However, pollution from point sources may be one of the most important factors causing localized defoliation. Factors explaining the variation in forest condition were not the same in different parts of the country, nor in different years. The most seriously defoliated, less than 60-year-old forests were located in southern Finland, which also has the highest deposition levels.

Compared to the situation in Central Europe, defoliation in Finland is moderate (Anon. 1990a). It is similar to that in the other Nordic countries (Anon. 1990c, Wulff & Söderberg 1990), but less than that recorded in the countries with the most severe forest damage such as Czechoslovakia. It is not possible, on the basis of five years' monitoring work, to draw any firm conclusions about whether the condition of our forests has essentially deteriorated or whether the increase in defoliation now observed is merely normal annual variation. According to long-term series of needle fall (Kouki & Hokkanen 1990), as well as studies on needle vascular bundles (Jalkanen & Kurkela 1990), the variation in the needle mass of trees has always been very high. No detrimental, long-term changes in tree growth have been detected in Finland (Nöjd 1990).

The most serious needle discoloration symptoms observed during the annual surveys were the chlorosis of the oldest needles on the upper part of the branches, and browning of the upper surface of needles. These symptoms may be due to increased light sensitivity of the needles. Connections between these symptoms and nutrient disturbances, e.g. magnesium deficiency, and the occurrence of elevated ozone levels or weather factors, require more detailed study.

There have been no outbreaks of forest death in Finland corresponding to those reported for Central Europe. However, single trees or whole stands have died in the immediate vicinity of industrial (e.g. Harjavalta) and densely populated areas. Dead trees are no longer a rare sight alongside main roads in Finland.

6. Conclusions

The effects of air pollution on forest ecosystems in Finland, either directly on the trees or indirectly through the soil, in relation to other causes, such as climate and disease, and their interaction, are at present still somewhat unclear. However, the northern location of Finland means that our forest ecosystems are extremely sensitive to any additional stress factor. Sulphur and ozone levels, especially, exceed the critical levels in almost the whole country, and nitrogen deposition is not far behind. If air pollution is not reduced below the critical level for forest ecosystems, the risk of serious forest damage will increase in Finland, too.

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SUOMEN METSIEN ELINVOIMAISUUS 1991

Metsäntutkimuslaitoksen vuoden 1991 kartoituksien mukaan viidennes Suomen metsäpuista on harsuuntunut eli menettänyt yli 20 % neulasistaan tai lehdistään. Tämän harsuuntumisrajan ylittäneitä mäntyjä on 8 %, kuusia 42 % ja lehtipuita 12 %. Männyn keskimääräinen neulaskato on 9 % ja kuusen 21 %. Harsuuntuneisuus on Ruotsin ja Norjan tasolla, mutta selvästi pienempää kuin pahimmin ilmansaasteiden vaivaamissa Keski- ja Itä-Euroopan maissa.

Seurantajakson alussa, vuosina 1986-1988, metsien harsuuntuminen lisääntyi Suomessa. Kolmen viimeisen seurantavuoden (1989-1991) aikana kuusen harsuuntuminen on pysynyt ennallaan, männyn ja lehtipuiden harsuuntuminen on vähentynyt. Kaikki puulajit huomioon ottaen harsuuntuminen on lisääntynyt 6 %-yksikköä kuuden vuoden aikana. Harsuuntuneimmat havupuut kasvavat Lapissa. Männyt ovat vähiten harsuuntuneita Keski-Suomen itäisissä osissa, kuuset Etelä-Suomessa.

Metsien harsuuntumiseen vaikuttavat metsien ikääntyminen sekä sää- ja ilmastotekijät. Versosurmaepidemiat ovat lisänneet männyn harsuuntumista Länsi-Suomessa. Ilman epäpuhtaudet ovat osaltaan vaikuttaneet harsuuntumisen lisääntymiseen Etelä-Suomen kuormitetuimmissa osissa. Epäpuhtauksien alhaisetkin pitkäaikaiset pitoisuudet voivat vaikuttaa haitallisesti puiden terveydentilaan pohjoisen kylmässä ilmastossa.

Vaikka metsäpuiden kasvukunto ja yleinen terveydentila ovat tyydyttävät, metsäekosysteemin herkimmissä osissa voidaan havaita erilaisia stressin oireita. Näitä seurataan vuosittain pysyvillä koealoilla.

Puiden oksilla ja rungoilla kasvavat jäkälät ovat metsäekosysteemin herkimpiä ilmansaasteiden indikaattoreita. Jäkälistä herkimpiä rikille ovat naavat ja lupot. Ne ovat väistymässä kuormitetusta Etelä- ja Keski-Suomesta. Sormipaisukarve on edellä mainittuja kestävämpi. Sitä havaittiin joka toisen tutkitun havupuun oksilla. Nuorimmat vuosikasvaimet, joilla sormipaisukarvetta esiintyi olivat 3 - 4 -vuotiaita.

Neulasten pinnalla kasvavaa leväpeitettä on havaittu usean vuoden ajan noin kolmasosalla tutkituista kuusista. Tämä kertoo kohonneesta typpikuormasta. Yleisimmin leväpeitettä esiintyy tuoreilla ja lehtomaisilla kankailla kasvavilla nuorilla kuusilla Etelä- ja Keski-Suomessa.

Kuivien ja karujen kankaiden on arvioitu olevan happamoitumisherkimpiä maita. Tällaisilla kasvupaikoilla alikasvoskuusilla havaittiin yleisesti oksien yläpinnan neulasten kellastumista ja keltakärkisyyttä. Oireiden taustalla saattaa kuivuusstressin ja kilpailun lisäksi olla ravinnehäiriö, jota maaperän happamoitumiskehitys voimistaa.