Forest Condition Monitoring in Finland – National report

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Forest condition in national networks (ICP Forests, Level I and Level II)

By Seppo Nevalainen & Martti Lindgren

Summary

Metla has carried out the large-scale crown condition survey (Level I) since 1986 (until 2012) and the intensive crown condition survey (Level II) since 1995. The main observed variables have been the degree of defoliation and foliage discolouration and the occurrence of abiotic and biotic damage to Scots pine, Norway spruce and broadleaves. The average tree-specific degree of defoliation for the period 1986–2012 on Level I sites was 10.7% in pine, 19.6% in spruce and 12.8% in broadleaves and for the period 1995–2013 on Level II observation plots 11.3% and 18.2% for pine and spruce, respectively.

The proportion of defoliated trees seems to have increased in the southernmost part of the country. In general, the proportion of discoloured spruces was higher and varied annually much more than that in pine or birch.In Level 1, the proportion of trees with symptoms of abiotic or biotic damage decreased during the monitoring period (1986–2012). The mean proportion of symptomatic trees was the same (60%) in all main tree species groups. Pines had less abiotic and unidentified damage, but more insect damage than spruce and broadleaved species. Level I data provides t emporal patterns and coarse spatial distributions of some of the most common causes of damage. The proportion of dead trees on Level I varied from 0.1 to 0.32%. High stand age, weather and climatic factors, as well as abiotic and biotic damage, have a considerable effect on defoliation in background areas of Finland.

Background

Concern about the largescale decline in forest vitality in Central Europe in the late 1970s and early 1980s led Finland to initiate an extensive national survey of forest conditions. The Finnish Forest Research Institute has surveyed crown conditions annually since 1986. The monitoring has been carried out in co-operation with the UN/ECE ICP-Forests-programme and, during 1995-2006, in accordance with EU regulations. Forest condition monitoring is carried out using international harmonized methods (Eichhorn et al. 2010, pdf).

This report presents a review of the results on forest condition monitoring in Finland. The results of extensive (Level I) and intensive level (Level II) surveys, as well as the annual variation in forest conditions and the regional distributions are presented, together with some interpretation of the apparent factors, which may explain the regional pattern and changes in forest conditions.

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Results: Extensive monitoring 1986–2012

Defoliation

The average tree-specific degree of defoliation for the period 1986–2012 on Level I sites was 10.7 in pine, 19.6 in spruce and 12,8 % in broadleaves. Across the whole country, the average tree-specific defoliation was at its highest during 1988–1989. Especially the defoliation degree of Norway spruce was at a particularly high level at this time. The defoliation of Scots pine slightly increased during the final years of the period 1986- 2008. The defoliation of both Scots pine and broadleaves (*Betula* sp.) showed a peak in 2007 (Fig. 1). The defoliation seemed to have increased during 2011 and 2012. However, the results from 2009-2012 are separate samples each year, and the results come from a different data network. Therefore the results are not directly comparable. In addition, peatland plots were only included in the 2004–2007 and 2009–2012 data.

Of all the trees assessed, 96% of the pines, 76% of the spruces and 92% of the broadleaves (*Betula* spp.) were not defoliated or were only slightly defoliated (leaf or needle loss was less than 25 % (see Fig. 2, pdf). The proportion of severely defoliated trees (defoliation more than 60%) has remained relatively constant. For pine this proportion was 0.5% and for spruce 2.4 % and for broadleaves 1%,

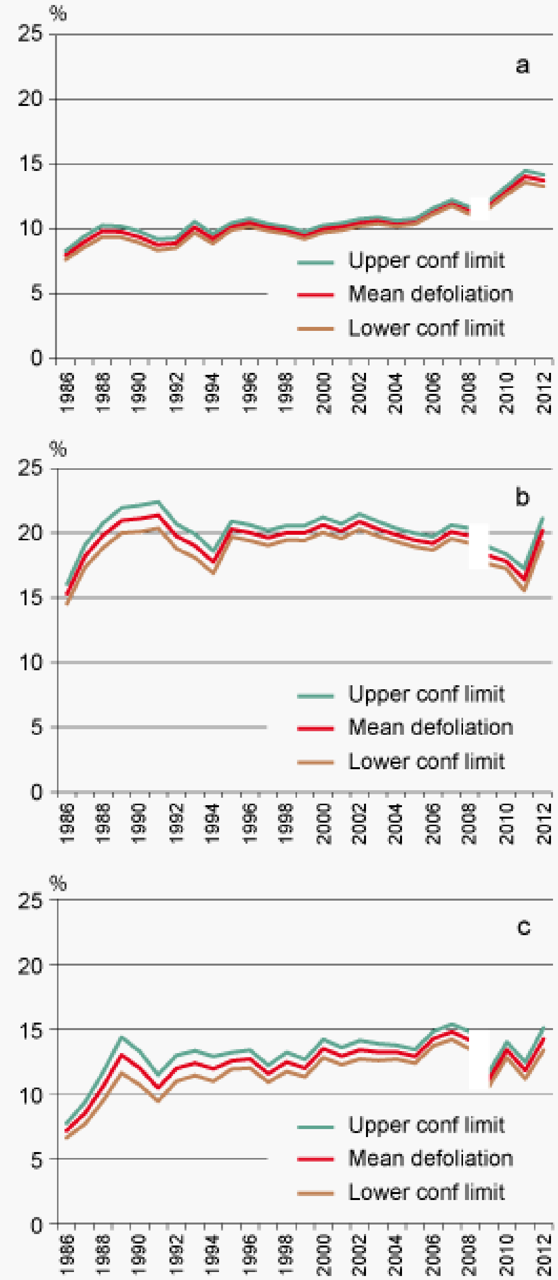

Figure 1 (a–c). Average degree of defoliation of Scots pine (a), Norway spruce (b) and birches (c), with 95% confidence intervals, in 1986–2012. Due to differences in sampling, the results for 2009 and 2010 are not directly comparable with each other or with the results from the previous years.

respectively, during 1986–2012.

Despite the relatively small changes in defoliation in the whole data, marked spatial and temporal variations in defoliation existed during the study period. The defoliation of pine in 2012 was highest in northeastern part of the country (Fig. 3b). In contrast, the highest defoliation values in 2008 were found in south-eastern Finland (Fig. 3a). The defoliation of spruce trees in 2012 was highest in Lapland and south-western Finland (Fig. 3d). In the 2008 data, the highest defoliation values in spruce were more scattered across the country (Fig. 3c). The highest values were found in the southernmost and the north-eastern parts of Finland. The defoliation of the assessed birch trees seems to have intensified in the very west-north (Figs. 3e and 3f).

The temporal pattern of defoliation seems to be different in relation to latitude. The proportion of defoliated (defoliation more than 10%) pines seems to increase in the southernmost zone (below 64 °N'), but has decreased clearly in the northernmost zone. The proportion of defoliated spruces showed a slight increase in the southernmost zone, and decreased in the two northernmost zones. The figures concerning the birches showed big variations in the north, and a slight increase in the southernmost zone (Fig. 4, pdf).

The result is confirmed in a trend analysis. In the 1986–2008 data, clearly more pine forests in the southern part of Finland showed an increasing defoliation trend than the pine forests in the northern part. However, the variation between adjacent sample plots was large. In spruce forests, the number of sample plots showing an increasing defoliation trend was also higher in the south than in the north. However, the difference between southern and northern areas was smaller for spruce than for pine (Figs. 5a and 5b).

The results from the latitude zones in 2009–2012 are not directly comparable with the 1986–2008 data, as mentioned earlier. There was an increase in pine and spruce defoliation in the northernmost zone, and in pine also an increase in the southernmost zone. The defoliation of birches continued to show large variation between the years 2009–2012.

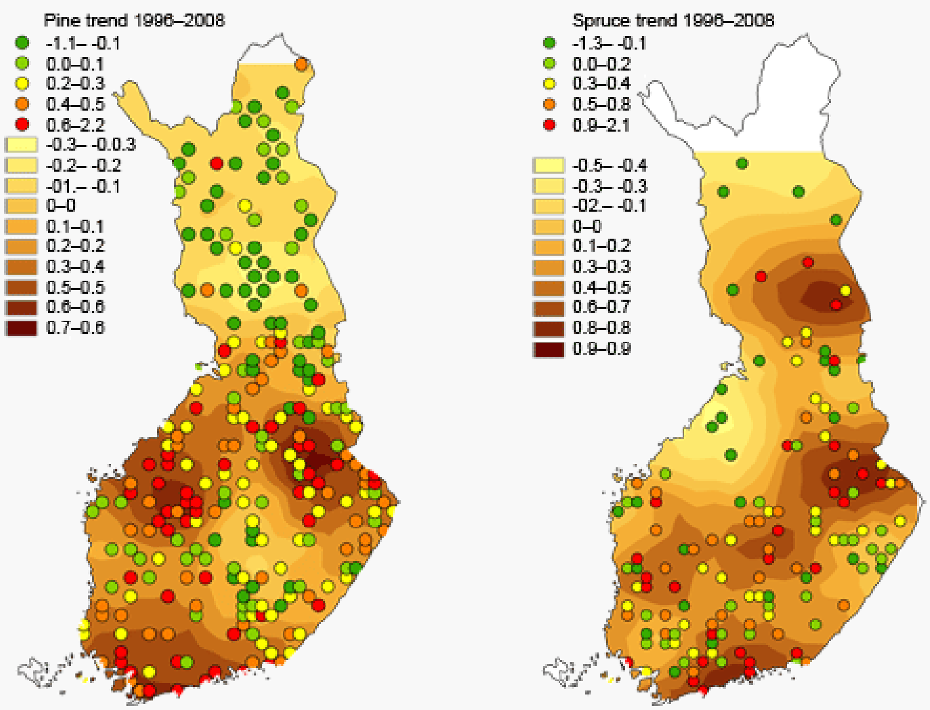

Figure 5 (a–b). The slope of the median (Theil-Sen) trend in the defoliation of Scots pine (a) and Norway spruce (b) in the common plots during 1995-2008. The trend analysis was done with the Earth Trend Modeler in Idrisi 16.05 (Taiga edition). The raster is produced with the kriging function in ArcMap 9.2, using a 30 km grid size, and the dots represent the slope values classified using a class width of ½ standard deviation in ArcMap.

Discolouration

In general, the proportion of discoloured spruces (the proportion of discoloured leaf or needle mass greater than 10%) was higher (8.3%) and varied annually much more than that in pine (1.4%) or birches (2.1%). The proportion of discoloured spruces was high at the beginning of the study period, the highest peak occurring in 1991 (20.4%). In 1989, the proportion of discoloured spruce trees was high in the western parts of Finland (Fig. 6, pdf). Later on, peaks in this proportion were recorded in 2005 and 2008. In pine, the proportion of discoloured trees remained at a low level in most years during the survey period, but it increased significantly in 2006, when the proportion was 6.8% At that time, discoloured trees were most frequently found in eastern Finland and along the south coast (Fig. 7, pdf). However, most of these discoloured conifers belonged to the 11% to 25% discolouration class, and the incidence of moderate or severe discolouration (discolouration over 25%) was rare (0.7% in all trees, 1.5% in the spruces). The most frequent discolouration symptoms in spruce were needle tip yellowing and needle yellowing, and in pine also needle browning. The colour symptoms were mainly concentrated on needles older than two years in spruce, and older than current-year needles in pine. Discolouration was also recorded as a damage symptom. Biotic and abiotic factors causing discolouration were recorded during the peak years, as reported later.

Biotic and abiotic damage

The proportion of trees with symptoms of abiotic or biotic damage decreased rather than increased during the monitoring period (1986–2012). The mean proportion of symptomatic trees was the same (60%) in all main tree species groups. Pines had less abiotic and unidentified damage, but more insect damage than spruce and broadleaved species (Table 1, pdf).

However, there were considerable changes in the occurrence of the agent groups and specified agents over the years (Fig. 8, pdf). Temporal patterns and coarse spatial distributions of some of the most common causes of damage were obtained on the basis of the annual Level I data.

In Scots pine, peaks in the occurrence of abiotic damage occurred in 1989 and 2006 (Figs. 7 and 8a, pdf). The latter peak was especially attributed to drought.

The proportion of Scots pine trees with symptoms was the highest (60%) in 1989. Higher-than-normal occurrence of damage by *Gremmeniella abietina* (Lagerb) Morelet (in the central and central-western parts of Finland), damage of the pine shoot beetles (*Tomicus sp.*) and edaphic factors were characteristic for 1989. Other high peak years in the new infections caused by *Gremmeniella* occurred in 1997 and 2001. During the highest peak of damage by pine sawflies in 2000 (here mostly *Diprion pini* L.), infection was reported in 7.3% of the assessed pines. Another massive epidemic of pine sawflies (this time mostly *Neodiprion sertifer* Geoffr.) became evident in 2008. A shift in the mass outbreak of pine sawflies from south-eastern parts of the country to the central- western parts was evident in the extensive level data in 2009–2010 (Fig 9). In 2012, the proportion of affected pines was again at low level, about 1 %. It should be noted that the results from 2009–2010 come from another monitoring network (permanent plots of the NFI 9), and are thus not comparable to the results from the older network (NFI 8) used between 1986 and 2008. Other examples of the epidemics in Scots pines include frost damage in 1989 in Lapland, the *Lophodermella sulgicena* Rostr. v. Höhn epidemics in central and central-eastern Finland and in Lapland.

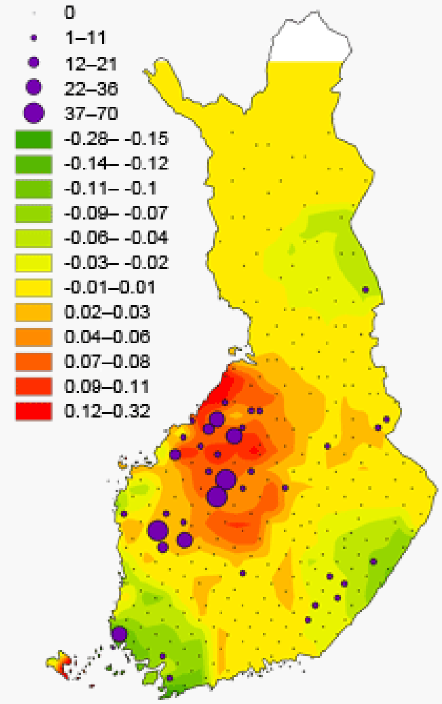

Figure 9. The occurrence of pine sawflies in 2010. The dots show the number of damaged trees per assessment tract. The raster shows the change in the occurrence between 2010 and 2009. Positive values (red) indicate an increase in the damage.

The proportion of Norway spruces with damage symptoms was the highest (60%) in 1988–89 (Fig. 8b, pdf), which was also reflected in the discolouration results (see above). In Norway spruces the peaks in fungal damage mostly reflect the infections caused by spruce needle rust (*Chrysomyxa ledi* (Alb. & Schw.) deBary). *Chrysomyxa* (18.4% of spruces) and frost damage (7.4%) were common in 1988. *Chrysomyxa* was also frequent in 1989, 2001 2005 and 2009, and also 2012 in northern Finland.

In birch trees, the most evident damage peaks occurred in 1993 (attributed to abiotic damage) and 2004, caused by birch rust, *Melampsoridium betulinum* (Pers.) Kleb., and by unidentified leaf-spot fungi (Fig. 8c, pdf).

It should be remembered, however, that most of the observed damage was slight. The proportion of moderate and severe damage was 5.1% for pine, 11.3% for spruce and 11.4% for broadleaves. The proportion of severe damage was 0.5% for pines, 0.8% for spruces and 0.9% for broadleaves. The yearly variation in this proportion was small. The moderate or severe damage in Scots pine was frequently caused by *Gremmeniella*, *Cronartium* sp., pine sawflies, especially *Neodiprion sertifer* and competition. In spruce the list of the most serious causes of damage consists of decay fungi, particularly *Heterobasidion* sp., unknown causes and competition. Unknown causes, snow, decay fungi and competition were the most important in birches.

Some spatial patterns were evident when the defoliation and biotic damage data were examined together. For instance, defoliation in pines increased slightly in 2000 in central Finland, which was also the area where pine sawflies (in this case mostly *Diprion pini*) were common.

Annual mortality

The mean annual mortality rate between 1986 and 2008 (i.e. the proportion of trees that had died after the previous year's inventory) were 0.16% for pine and 0.18% for spruce. The values ranged from 0.092% in 1985–87 to 0.32% in 1988 and 2002. The dead trees were very evenly distributed throughout the whole country. The relatively high proportion of dead spruces in 2002 was due to the larger number of trees damaged by storms (68%) compared to the situation in other years. In general, wind, snow and *Heterobasidion* sp. were the most common causes of tree mortality.

Material and methods

The large-scale crown condition survey (Level I) has been carried out in Finland on a systematic network of permanent sample plots since 1986, until 2012. Before 2009, a subsample of the permanent plots established during 1985–1986 in connection with the 8th National Forest Inventory (NFI) was used (Jukola-Sulonen et al. 1990).

The integration between ICP Level 1 and NFI was accomplished in 2009 in Finland. The sampling design of the current NFI is a systematic cluster sampling. The distance between clusters, the shape of a cluster, the number of field plots in a cluster and the distance between plots within a cluster vary in different parts of the country. Principally, every fourth cluster is marked as a permanent cluster. Annually, a new set of permanent plots, established during the 9 th NFI in 1996–2003, is assessed in the forest condition survey. Tallied dominant and co-dominant Norway spruce, Scots pine and birch trees from six pre-selected permanent plots from each cluster were assessed. The same permanent plots were to be assessed at five-year intervals. In 2009, all trees were assessed, but -since 2010 a maximum of six trees per appropriate species were included in the sample., which led to a reduction in the number of assessed trees.

Please note that because the plots assessed during 2009–2012 were completely different samples, the results from 2009– 2012 are not directly comparable with each other or with the results from the previous years.

The number of assessed plots and trees at the extensive level (1986–2010) are described in Table 2, pdf.

The most important variables used to describe crown condition were defoliation, discolouration of the crown and abiotic and biotic damage. These variables were assessed visually according to internationally standardized methods (Eichhorn et al. 2010, pdf) and national field guidelines (Lindgren et al. 2005). Defoliation is expressed as the relative leaf or needle loss compared to a reference tree (Lindgren et al. 2000).

Defoliation of Norway spruce was estimated on the upper half of the living crown, and of Scots pine (*Pinus sylvestris* L.) and birches (*Betula* sp.) on the upper two-thirds of the living crown in 5% of classes. The proportion of discoloured needle mass (e.g. needle tip yellowing, needle yellowing and browning) was assessed in five classes (class 1 = 0–5%, 2 = 6–10%, 3 = 11–25%, 4 = 26–60% and 5 = more than 60%). A tree is classified as discoloured when 10% of its leaf or needle mass has abnormal colouration. Please note that in 2010 discolouration was not recorded as a separate variable (but it was included in the damage assessment).

A national system for the description of a symptom, apparent severity (degree of damage) and the cause, as well as the age of the damage, was used prior to 2004. An example of the variables and codes used in the national damage survey before 2004 can be found in Nevalainen (1999) and Lindgren (2002), for example. The ICP Forests manual of damage causes (Eichhorn et al. 2010), was tested in 2004, and fully adopted in 2005 in Finland. Currently, the European assessment of damage consists of symptom description, determination of the causal factor and quantification of the symptoms (extent of damage). The age of the damage (new or old) was also recorded. Several injuries can be recorded for each tree. The principles of the national damage survey in Finland were similar to the international guidelines, except that the coding of damage symptoms and causes used to be less detailed, and the quantification of damage was not systematically used prior to 2004.

In addition to the analysis of all nationwide data, the temporal development of defoliation was also analysed in four different latitudinal zones. The approximate upper latitude limits of the zones were as follows: Zone 4 (the southernmost): 62° N, zone 2: 64 ° N and zone 3: 67 °N (see Salemaa et al. 1990). The generalization of the mapped data was done using the kriging function in ArcMap 9.2. In addition, a trend analysis was computed with the Earth Trend Modeler in Idrisi 16.05 (Taiga edition), and the median (Theil- Sen) slope estimates were used in this study.

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Results: Intensive monitoring 1995–2013

Defoliation

The average tree-specific degree of defoliation for the period 1995–2013 was 11.3% and 18.2% for Scots pine (total 18 sample plots) and Norway spruce (total 15 sample plots), respectively. The crown condition parameters were assessed in every year only in four pine plots and five spruce plots (table 3, pdf). The proportion of non-defoliated (defoliation less than 10%) Scots pines was 64.9%, and that of Norway spruces 31.5% in the intensive observation plots. In addition, the proportion of moderately or severely defoliated spruces was clearly higher in spruce than in pine (3.9% for pine and 14 % for spruces). During the monitoring period there has been a shift from the 0–10% defoliation class to class 11–25%, due to ageing of the trees.

However, the number of sample plots varied annually during the monitoring period. The low average tree-specific degrees of defoliation (under 5%) in pine was detected e.g. on the Kivalo (plot number 6) in 1995, 1997, 2003 and 2004, on Punkaharju (number 16) in 1999, 2000 and 2001, and on Tammela (number 13) in 2000. The slight or moderate average tree-specific degrees of defoliation (more than10%) were detected in 11 pine plots e.g. on the Sevettijärvi (number 1) and Lieksa (number 20) (please see the interactive Fig.10).

In Norway spruce plots the average tree-specific defoliation was mostly over 10% during the period 1995-2013, with the exceptions of e.g. Juupajoki (number 11) in 1995, 1996 and 1999 (Fig. 10). The highest average tree-specific degrees of defoliation (more than 25%) was detected e.g. on the Evo plot (number 19) in several years during the monitoring period. There was no clear simultaneous increase or decrease in defoliation between Level II observation plots. Rather, the defoliation shows large plot-wise annual variations in the intensive level, too.

The estimated non-parametric monotonic trends (Theil-Sen) usually show a positive trend (increasing defoliation). However, the linear trend was sometimes not significant, because there were sudden annual peaks in defoliation, due to abiotic or biotic damage. The largest significant positive trend was observed on plot number 16 (Norway spruce plot in Hyytiälä) (table 3, pdf).

Discolouration

The proportion of discoloured Scots pines (proportion of discoloured needle mass more than 10%) was very low throughout almost the entire monitoring period 1995-2013 (Fig.10). On average 98% of Scots pines belong to the discolouration class “non-discoloured” (extent of discoloured needle mass 0–10%) during the monitoring period. However, an increase in proportion of discoloured (extent of discoloured needle mass more than 10%) Scots pines was detected in 1999, 2008 and especially in 2006 (see also the results from the extensive level above). However, most of the discoloured Scots pines belong to the 11 to 26% discolouration class and the incidence of moderate (extent of discoloured needle mass 26–60%) or severe (extent of discoloured needle mass more than 60%) discolouration was rare.

In Norway spruce, the proportion of discoloured (extent of discoloured needle mass more than 10%) trees was generally higher and more varied than in Scots pine during the whole monitoring period (Fig.10). In general, 90% of spruces were classified as non-discoloured during 1995–2013. The lowest proportion of non-discoloured spruces (79.4%) was detected in 1996. In the same year, the proportion of moderate and severe discoloured (extent of discoloured needle mass 26–60% and over 60%, respectively) spruces was highest. The proportion of slightly discoloured spruces varied from 0.4% (in 2010) to 15% (in 1999) and was more than 10% in 1995, 1996, 1999, 2000, 2005, 2008 and 2012. There was no clear simultaneous increase or decrease in discolouration between Level II observation plots. Rather, the discolouration shows large plot-wise annual variations. The highest amount of discoloured trees in the plots assesses every year was detected in Pallasjärvi (number. 3) in 1996 where 65% of spruces were discoloured.

Biotic and abiotic damage

In the intensive monitoring plots, biotic and abiotic damage is reported for pine and spruce trees (Fig.10).

As in the extensive monitoring, pine trees had less abiotic damage, but more insect damage than spruce trees. Large annual variations in the occurrence of some main biotic/abiotic causes existed, even in the scarce intensive plot network (Fig.10). The most apparent peaks were due to insect damage, mainly pine sawflies in pine stands (2000) and the high occurrence of fungal diseases in spruce stands (1997 and 1999–2001), and in the spruce stands 3 and 5 in the north also in 2011–2013. Abiotic damage was common e.g. in Scots pine plot 22 in Kevo in 1997–98. The spruce plot number 11 suffers from attacks by bark beetles (Ips. sp) and infection by rot fungi. In addition, spruce plot number 17 in Punkaharju was partly infected with *Heterobasidion parviporum* (Niemelä & Korhonen), and many trees were wind-thrown during the storms in 2013.

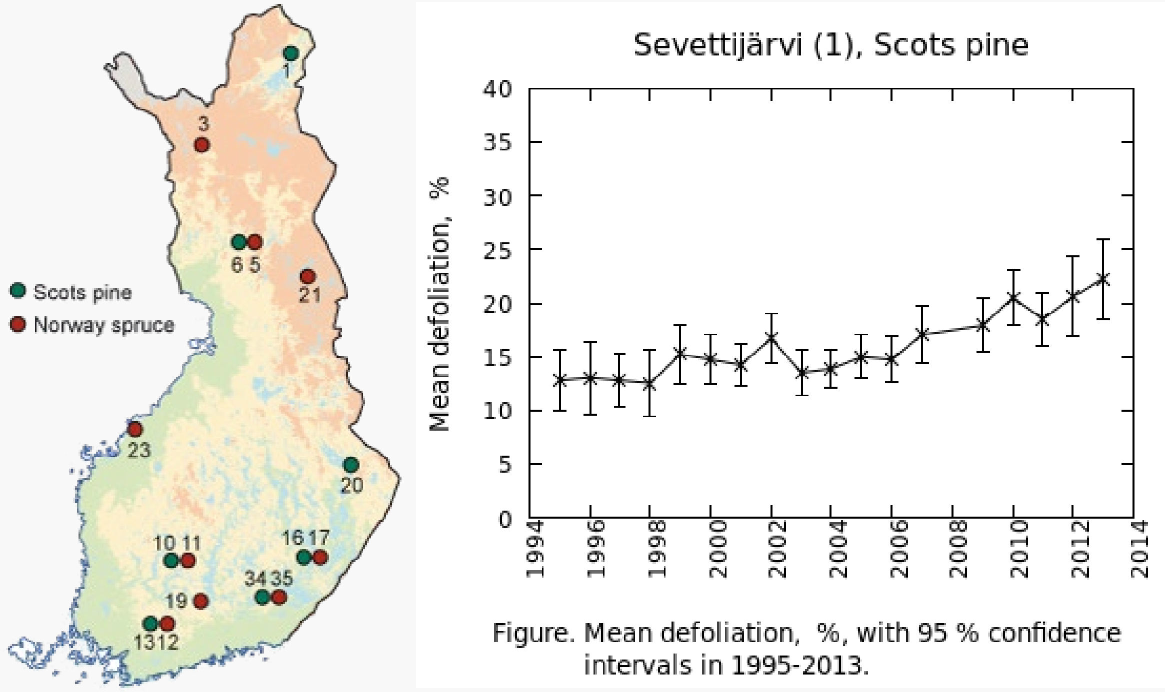

Figure 10. Please click the plot location on the map (left) and choose the variable to be shown in the graph (right). Please note that plots 1, 19, and 21 were not assessed in 2008.

Material and methods

The annual crown condition assessment was carried out on the Scots pine and Norway spruce and birches intensive monitoring observation plots from 1995. Defoliation, foliage discolouration, and abiotic and biotic damage were assessed on twenty trees on each sub-plot. Depending on the design of the observation plot (see design of the observation plots in Chapter 1), the total number of sample trees per plot varied from 40 to 60. Principally, dead trees were replaced by new trees in the next years's assessment. Moreover, the number of assessed observation plots and trees varied during the monitoring period (see Chapter 1). The assessment of sample trees was carried out according to the ICP Forests manuals (see Eichhorn 2010, pdf). However, instead of whole crown assessment introduced in the ICP Forests manuals, the defoliation and discolouration of spruce were estimated on the upper half of the living crown, and of birch and pine on the upper two-thirds of the living crown in 5% of classes in the same way as in Level I in Finland. Since summer 2004 the new method for damage assessment was applied. In addition to the ICP Forests manual, national field guides were used in intensive monitoring. The Theil-Sen slope, a robust estimator for the magnitude of the linear trend (median of slopes between all data pairs) (Gilbert 1987) was calculated using an Excel macro by Grimwall (Swedish University of Agricultural Sciences).

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Discussion

The monitoring of forest condition has undergone significant changes in recent years in many countries, including Finland. The extensive level survey is now integrated in the NFI. This has the advantage of a more representative sample. On the other hand, the annual time series is lost. This is not so harmful for the time series of defoliation itself, because the variation between the years in defoliation has been found to be negligible compared to the between-plot and other sources of variation (Nevalainen et al. 2010). In the new system, annual records of biotic and abiotic damage, which may explain defoliation, cannot be obtained tree-wise annually, but can be computed for an area (as an example, see Fig. 9). Annual data can now only be obtained from the intensive monitoring plots, but their number has decreased due to restrictions in national funding.

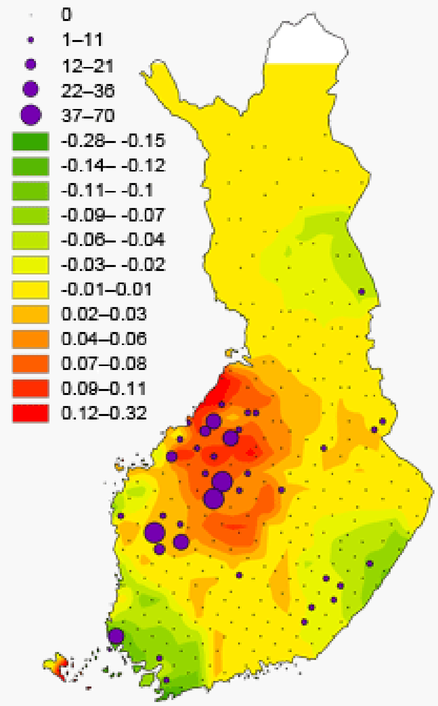

Figure 9. The occurrence of pine sawflies in 2010. The dots show the number of damaged trees per assessment tract. The raster shows the change in the occurrence between 2010 and 2009. Positive values (red) indicate an increase in the damage.

The defoliation method, regularly used to record forest health, has several disadvantages, despite its practicality. Leaf biomass of the crown is greatly affected by tree age, climatic and genetic factors, shading and many abiotic or biotic stresses. We have very little research information about the natural variation of leaf biomass (Westman and Lesinski 1986, Lesinski and Westman 1987, McKay 1988). Older stands are more defoliated than younger stands. In Finland, the mean age of the stand explains more than half of the between-plot variance in defoliation (Nevalainen et al. 2010).

In some country reports, the rapid deterioration in the vitality of forests has been attributed to abiotic or biotic damage (Hütte 1986, Keane et al. 1989, Roloff 1991, Innes and Schwyzer 1994). It has even been suggested that beyond some special pointer years, when growth conditions have been extremely poor, the results from forest health surveys merely reflect the effects of abiotic and biotic damage (Kandler 1989).

In Finland, a large number of natural factors, the most important of which are connected with stand age, climate, weather, and abiotic or biotic damage, affect forest condition (Jukola-Sulonen et al. 1990, Salemaa et al. 1991, Lindgren et al. 2000, Nevalainen & Heinonen 2000). In the northern parts of the country in particular, the harsh climate has a strong effect on forest development. At the beginning of the monitoring period, the increase in defoliation coincided with the extremely cold winter of 1987, and defoliation increased in all tree species between 1986 and 1989. Despite a slight increase in defoliation at the beginning of the study period, the abrupt changes in forest condition during the past 25 years are most often caused by abiotic and biotic stress factors. The intensity of the epidemics vary from year to year, and spatial patterns can change quite rapidly. An example of the local correlation analysis, discussed above (Nevalainen et al. 2010), demonstrated that biotic/abiotic damage can, at the regional level, be strongly correlated with the changes in defoliation. However, some local damage will not be revealed in our sparse monitoring network. These include storm damage and epidemics by bark beetles, especially *Ips*- species in spruce.

The relatively low proportion of severely defoliated conifers and the small number of dead trees, as well as the causes of tree death (primarily storms, snow and chronic decay fungi), suggest that no widespread forest decline was detected in our study in Finland.

The results concerning discolouration are somewhat problematic, because there has been some uncertainty in the international guidelines. Nowadays, some countries do record discolouration as a separate variable, while others record discolouration as a part of the damage symptom, to avoid double markings. The latter approach was adopted in Finland in 2010 in both Level I and Level II. The results from the two approaches do not appear to be comparable. In Central Europe the discolouration of spruce is often connected to the nutrient disturbances such as magnesium or potassium deficiency (Zöttl and Hüttl 1989). One should remember, however, that the visible symptoms are non-specific, and they often express interaction between several factors (Wulff et al. 1996, Aamlid 1997, Solberg and Tørseth 1997). In our crown condition surveys in Finland the extensive discolouration in many cases seems to be connected to very dry summers (e.g. 2006) and fungal diseases. A slight discolouration of older needles is very difficult to interpret due to its unspecific nature, and slight discolouration in spruce needle tips, for example is easily masked by fungal infections.

Our monitoring results seem to suggest that the main immediate threats to the health and condition of Finland's forests are abiotic and biotic factors, such as storms, drought, insect pests and fungal pathogens. The interactions between stress factors and biotic damage can be very complex, however, and utmost care should be taken in interpreting the forest vitality results (Pearce 1994, Thomsen and Nellemann 1994). Oak decline in Central Europe is a good example of a disease with a complex etiology (Thomas et al. 2002). The stress approach by Manion (1991) is still very relevant. In Finnish conditions, tree age and unfavourable soil conditions (not forgetting the long-term effects of air pollution) can act as predisposing factors. Insect defoliation, infections by *Gremmeniella*, extreme drought, mechanical injury or frost damage may be the most common inciting factors, while bark beetles or root-decay fungi may act as contributing factors. The increasing defoliation trend in the southern parts of the country, suggested in this report, warrants an in-depth-study.

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Table 1. The occurrence of groups of causal agents on the extensive (Level I) network plots in Finland during 1986–2012.

Causal agent group	Mean occurrence (% of trees)			
	Scots pine	Norway spruce	Birches	All tree species
No damage	61.1	61.4	61.4	61.2
Mammals	0.6	0.1	1.2	0.6
Insects	10.0	0.2	5.2	6.3
Fungi	9.8	9.5	7.1	9.3
Abiotic	3.8	7.1	6.5	5.2
Direct action of man	1.8	3.4	2.0	2.3
Other*	9.8	10.8	10.3	10.2
Unknown	3.2	7.4	6.2	4.9
Total, %	100	100	100	100
Number of observations	105,392	58,671	31,150	195,213

*mainly competition

Table 2. The number of assessed trees, sample plots and observers in the extensive (Level 1) forest condition monitoring during 1986–2012. The number of plots includes also peatland plots during 2004, 2007 and 2009–2012.

Year-Vuosi	Number of trees	Scots pine	Norway spruce	Broadleaves	Number of plots	Number of observers
1986	3982	2233	1445	304	378	4
1987	3971	2171	1432	368	376	4
1988	3870	2129	1391	347	370	4
1989	3807	2032	1355	500	360	4
1990	3746	2002	1329	415	358	4
1991	3764	2004	1272	488	356	4
1992	4391	2377	1367	647	409	4
1993	4276	2347	1307	622	399	4
1994	4180	2301	1265	614	392	4
1995	8754	4520	2838	1396	455	7
1996	8732	4522	2851	1359	455	7
1997	8779	4582	2814	1383	460	7
1998	8758	4584	2829	1345	459	8
1999	8662	4538	2816	1308	457	8
2000	8576	4560	2706	1310	453	8
2001	8579	4608	2693	1278	454	8
2002	8593	4648	2691	1254	457	9
2003	8482	4610	2622	1250	453	10
2004	11210	6174	3123	1913	594	11
2005	11535	6450	3089	1996	609	11
2006	11506	6469	3045	1967	606	11
2007	11199	6331	2980	1888	593	12
2008	8819	4828	2557	1434	475	10
2009	7176	4186	1805	796	886	14
2010	7946	4387	2206	1353	932	15
2011	4217	2252	1104	861	717	15
2012	4676	2571	1187	918	785	15

Table 3. Defoliation in the intensive monitoring plots. Only plots which were assessed after 2009 are shown. The 'defoliation mean' column also shows the 95% confidence interval of the mean. The Theil-Sen slope is a robust estimator for the magnitude of the linear trend (median of slopes between all data pairs) (Gilbert 1987).

Plot number	Location	Tree species	Defoliation mean, %	Defoliation s.d.	Theil-Sen slope	p-value	First year	Last year	Number of years	Number of trees
1	Sevettijärvi	*Scots pine*	15.9±0.66	9.10	0.430	0.000	1995	2013	18	738
3	Pallasjärvi	*Picea abies*	20.5±0.65	11.13	0.460	0.001	1995	2013	19	1129
5	Kivalo	*Picea abies*	16.2±0.41	7.04	0.144	0.090	1995	2013	19	1140
6	Kivalo	*Scots pine*	6.9±0.35	6.09	0.269	0.001	1995	2013	19	1142
10	Juupajoki	*Scots pine*	11.4±0.31	5.38	0.386	0.000	1995	2013	19	1140
11	Juupajoki	*Picea abies*	14.6±0.70	12.16	0.664	0.000	1995	2013	19	1148
12	Tammela	*Picea abies*	15.3±0.52	9.01	0.479	0.000	1995	2013	19	1144
13	Tammela	*Scots pine*	6.6±0.25	4.24	0.258	0.000	1995	2013	19	1130
16	Punkaharju	*Scots pine*	8.1±0.44	7.67	0.429	0.002	1995	2013	19	1141
17	Punkaharju	*Picea abies*	18.7±0.58	10.01	0.334	0.001	1995	2013	19	1131
19	Evo	*Picea abies*	27.8±0.82	10.99	-0.221	0.400	1996	2013	17	684
20	Lieksa	*Scots pine*	25.2±0.78	10.69	0.374	0.000	1996	2013	18	721
21	Oulanka	*Picea abies*	22.9±0.89	10.86	0.053	0.600	1996	2010	14	573
23	Uusikaarlepyy	*Picea abies*	11.1±0.59	8.75	0.458	0.001	1996	2010	14	843
34	Luumäki	*Scots pine*	10.8±0.68	5.98	0.802	0.300	2009	2013	5	300
35	Luumäki	*Picea abies*	16.0±0.79	6.97	0.682	0.050	2009	2013	5	300

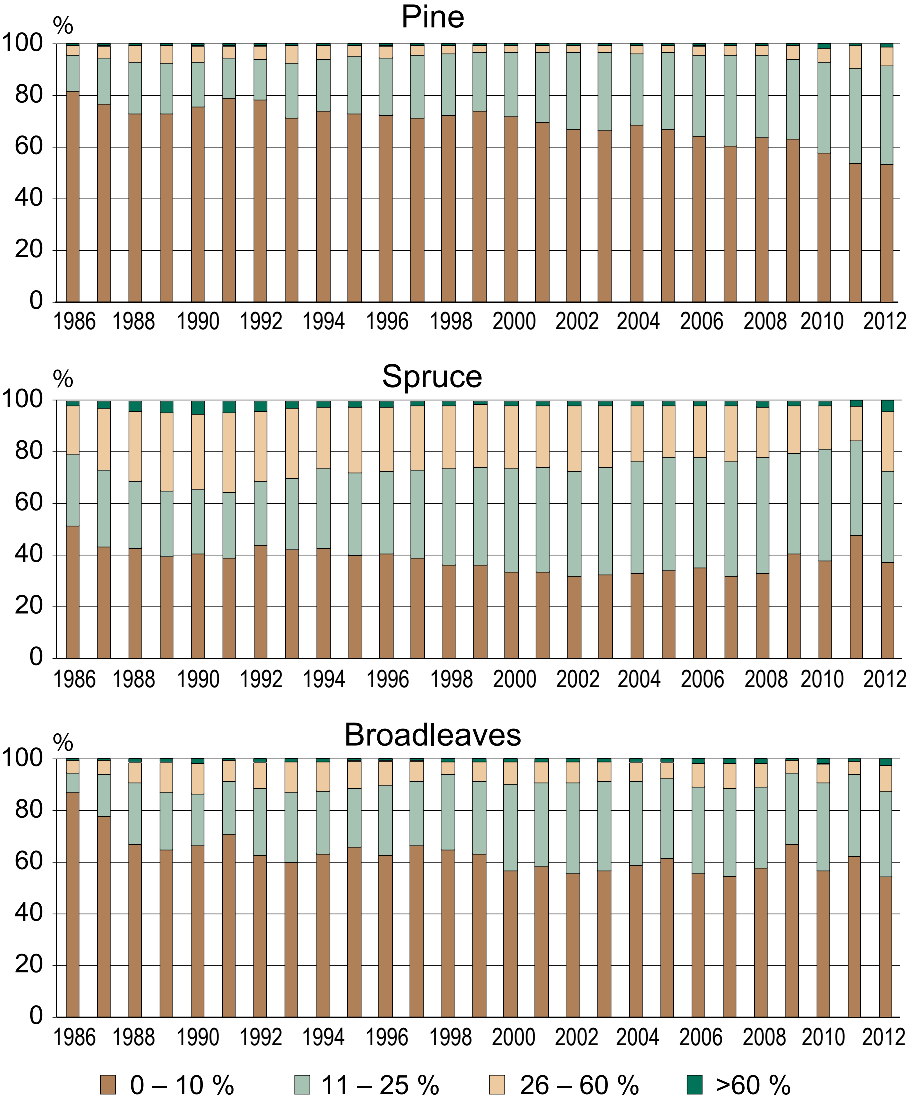

Figure 2. Frequency distributions of the defoliation classes for Scots pine (A), Norway spruce (B) and broadleaves (C) during 1986–2012. *N.B*. The plots assessed in 2009–2012 come from a different sampling network, and are completely different samples. Therefore, the results after 2009 are not directly comparable with each other or with the results from the previous years.

Figures 3a–e

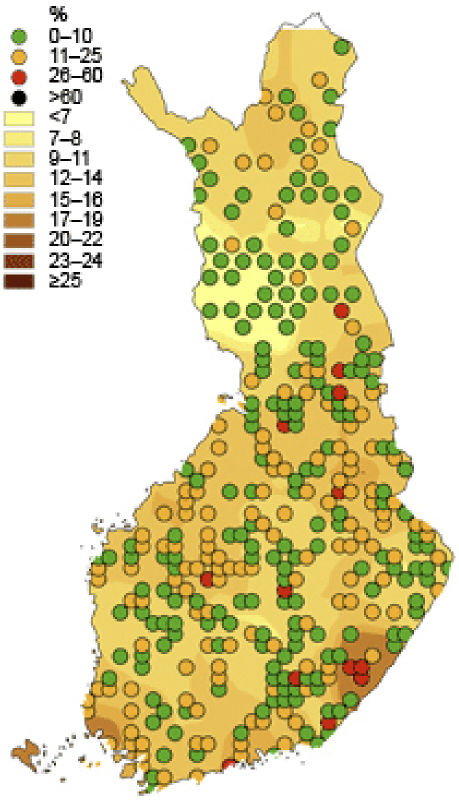

Figure 3a. The defoliation of Scots pine trees in 2008.

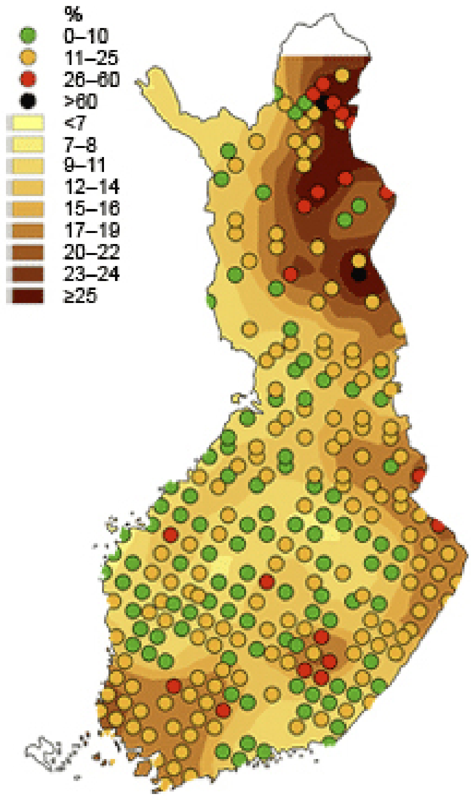

Figure 3b. The defoliation of Scots pine trees in 2012.

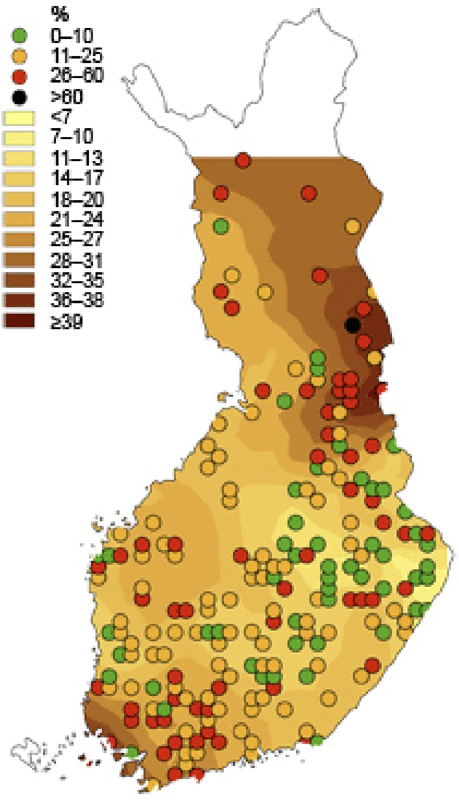

Figure 3c. The defoliation of Norway spruce trees in 2008.

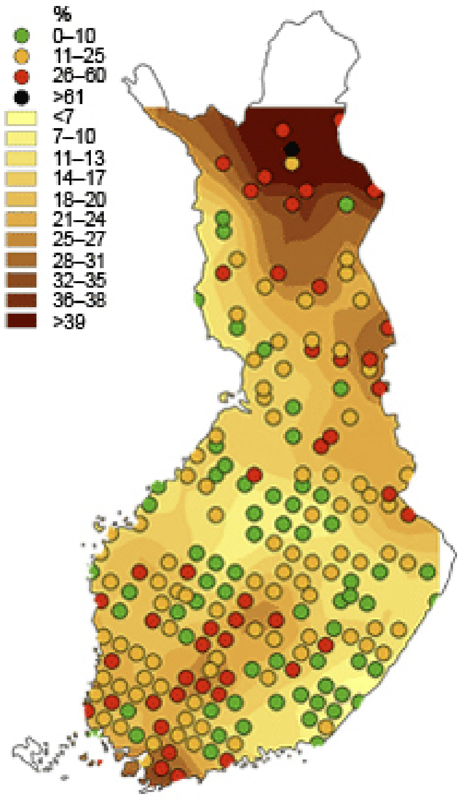

Figure 3d. The defoliation of Norway spruce trees in 2012.

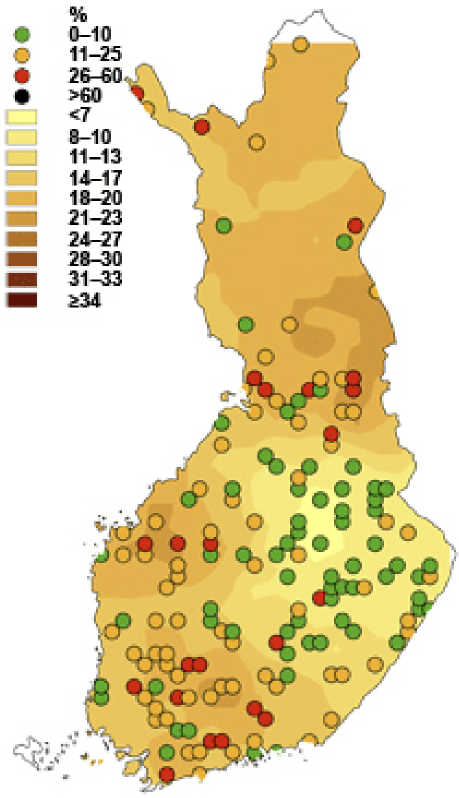

Figure 3e. The defoliation of birch (*Betula* sp.) trees in 2008.

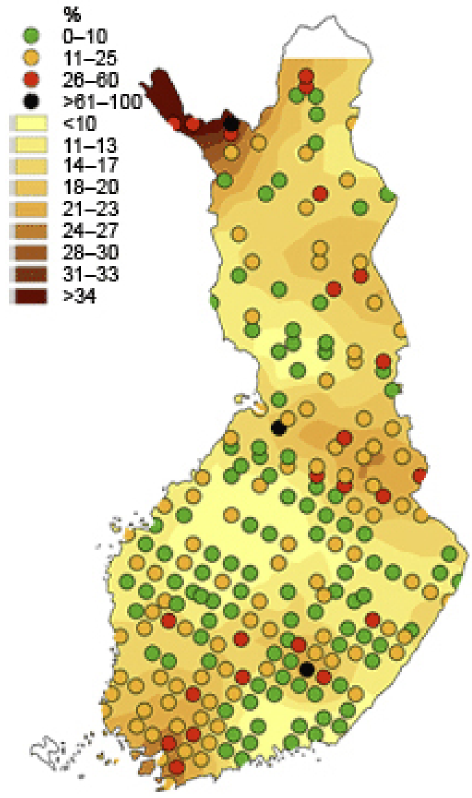

Figure 3f. The defoliation of birch (*Betula* sp.) trees in 2012.

The rasters are produced with the kriging function in ArcMap 9.2, using a 30 km grid size. The dots represent the mean defoliation class of trees in the plots (2008) or in the tract (2012).

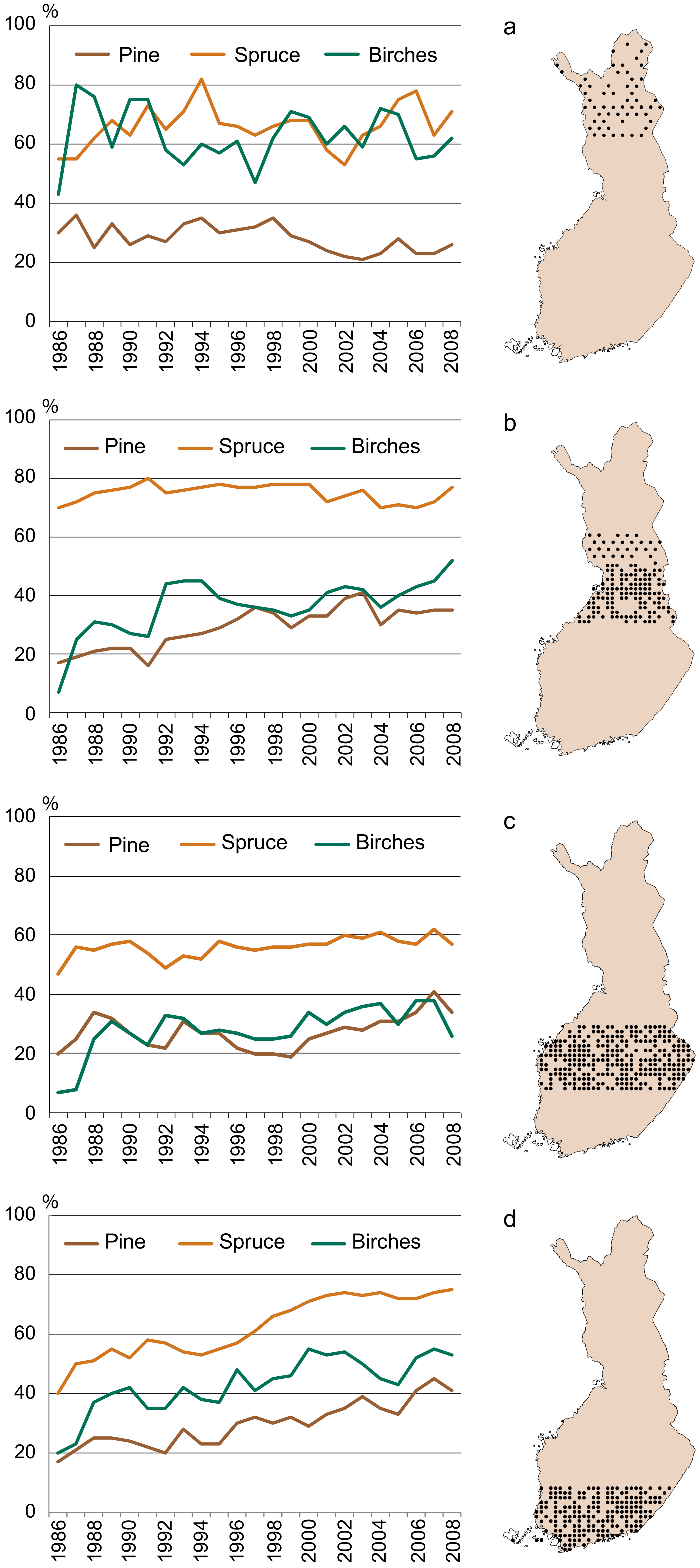

Figure 4. Proportion of Scots pine, Norway spruce and birch trees defoliated >10% in Finland in 1986–2008. The results are presented for four zones of the country from north (a) to south (d). The small maps show the locations of the extensive monitoring plots in the zone in question. The approximate lower latitude limits of the zones were as follows: a. (the northernmost zone) 67°N, b. 64°N, c. 62°N (see Salemaa et al. 1990).

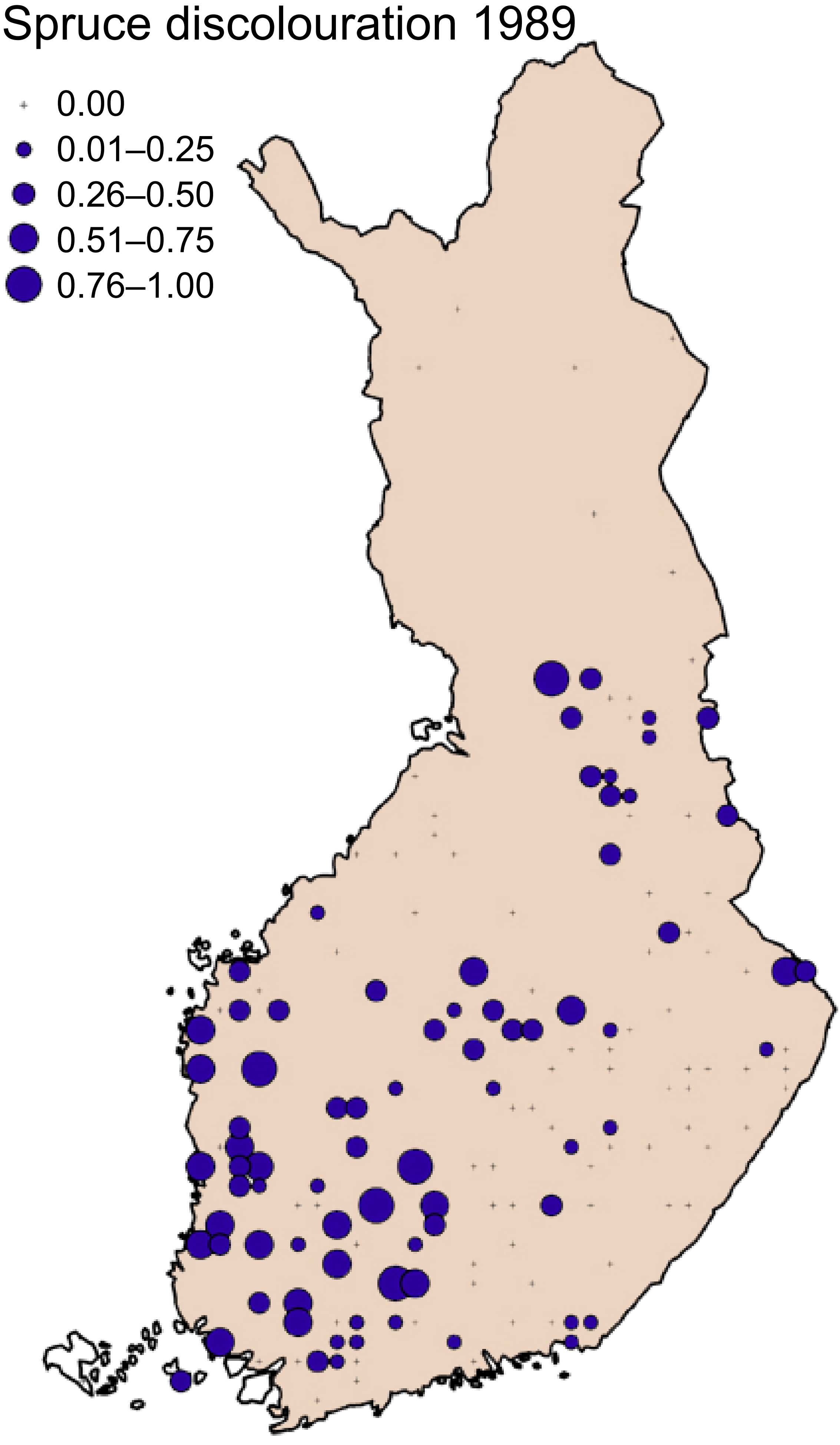

Figure 6. The proportion of Norway spruce trees (per plot) with discolouration greater than 10% in 1989.

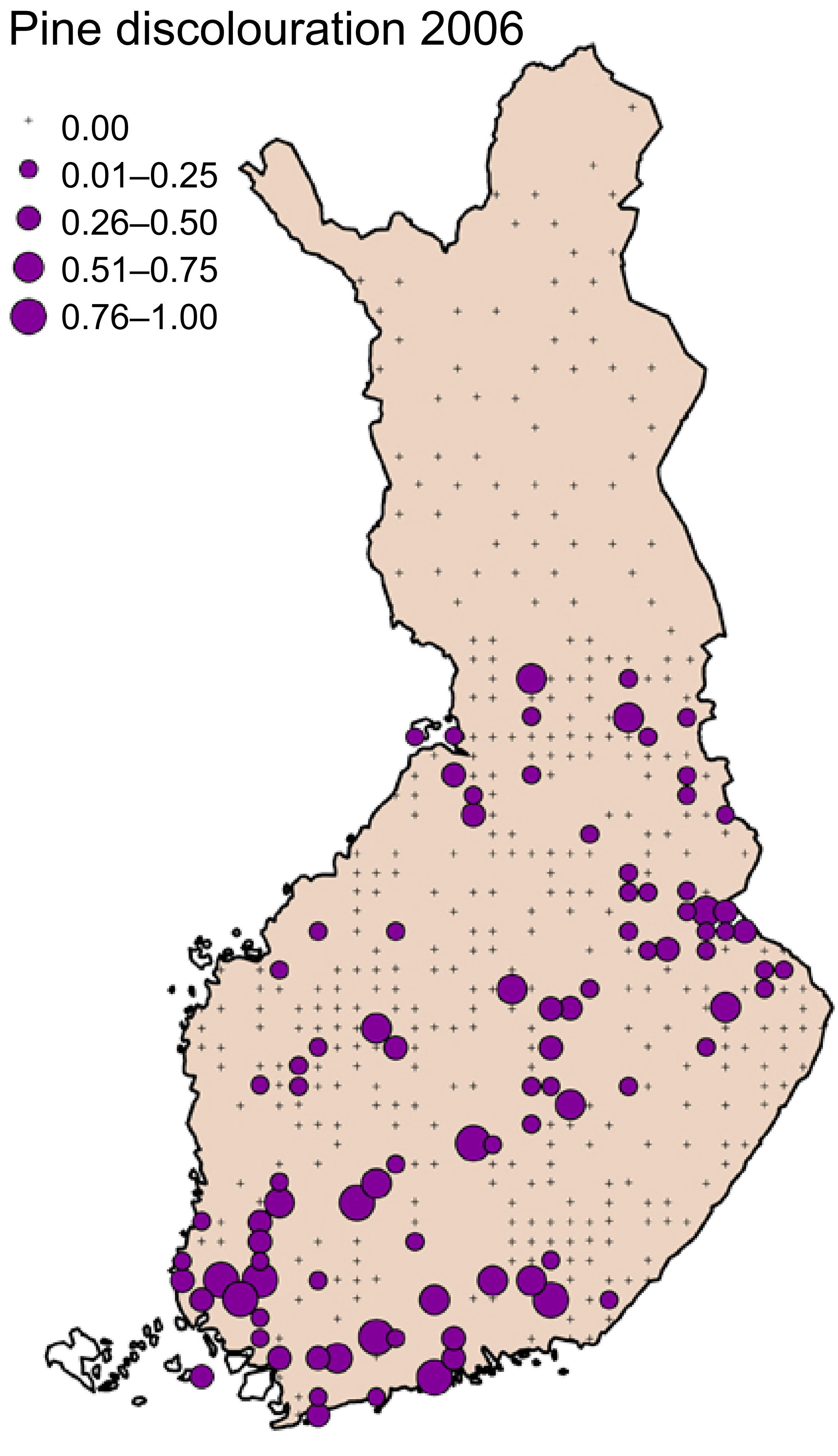

Figure 7. The proportion of Scots pine trees (per plot) with discolouration greater than 10% in 2006.

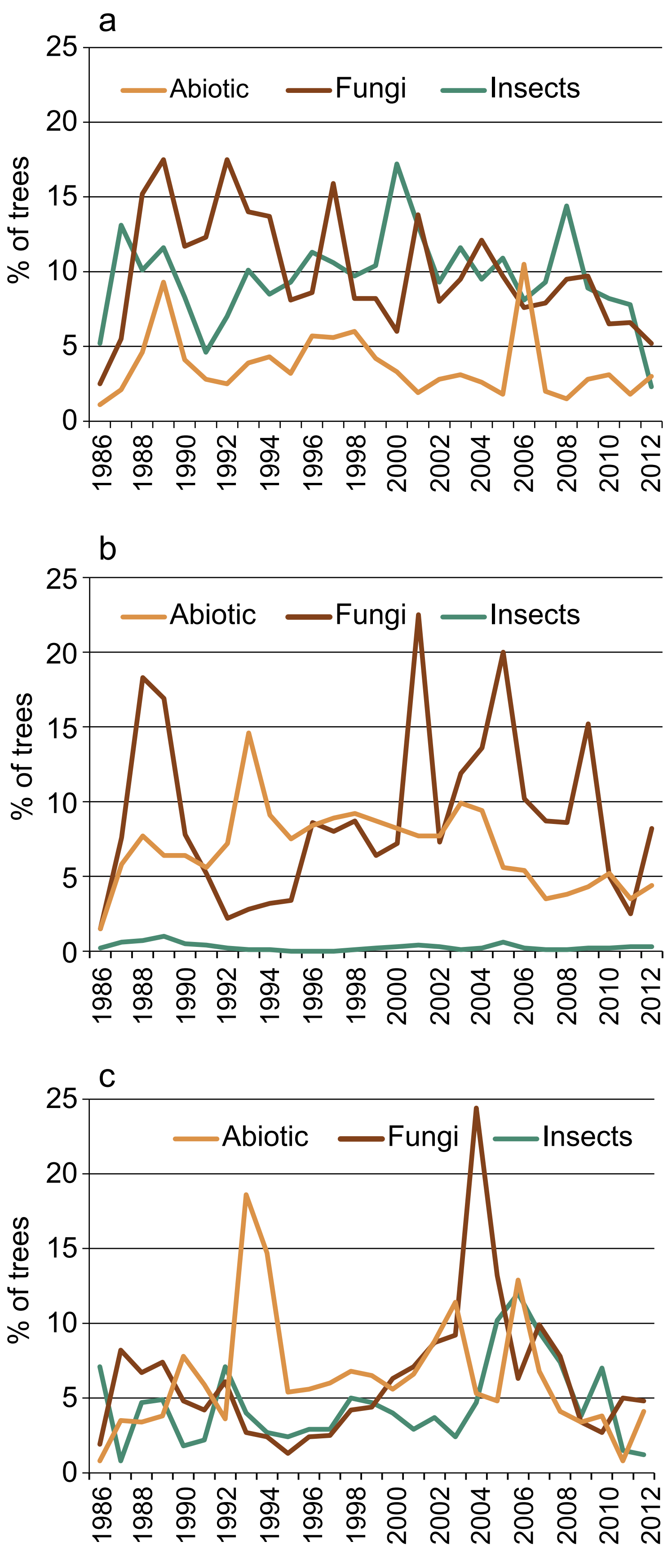

Figure 8. Annual occurrence of the most important groups of causal agents in the extensive level 1986–2012. a) Scots pine, b) Norway spruce, c) birches.