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Spatial and Temporal Variation in the Occurrence of *Gremmeniella abietina* in Scots Pine in Finland

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Abstract – Spatial and temporal patterns in the occurrence of the infections caused by *Gremmeniella abietina* in Scots pine stands in Finland during the years 1985-2005 were described in this paper The study utilized data from forest health monitoring plots (Forest Focus Level I plots) and permanent and temporal plots of the National Forest Inventories. The National Forest Inventories showed that the disease was far more common in southern than in the northern parts of the country. The disease was also clearly spatially clustered. The proportion of diseased stands decreased between the 8th NFI (1986-1994) and 9th NFI (1996-2003). The forest health monitoring revealed a heavy outbreak of *Gremmeniella* in 1988-89, and smaller peaks in 1997 and 2001. Temporal and spatial distributions of the disease were obtained using the level I data. The usability of various datasets were also compared with each other.

forest health monitoring / national forest inventory / forest diseases / *Pinus sylvestris* / *Gremmeniella abietina*

Kivonat – A *Gremmeniella abietina* előfordulásának térbeli és időbeli változása az erdeifenyőn Finnországban. A dolgozat a *Gremmeniella abietina* előfordulásának térbeli és időbeli mintázatát ismerteti a finnországi erdeifenyő állományokban, az 1985-2005 időszakban. Felhasználtuk az erdők egészségi állapotfelmérő mintaterületeinek adatait (Forest Focus I mintaterületek) és a Nemzeti Erdőleltár állandó és időszakos mintaterületeit. A Nemzeti Erdőleltár adatai szerint az ország déli részén a betegség messze gyakoribb volt, mint északon. A 8. Nemzeti Erdőleltár (1986-1994) és a 9. Nemzeti Erdőleltár (1996-2003) közötti időszakban a beteg állományok aránya csökkent. Az erdők egészségi állapotfelvétele a *Gremmeniella* erős kitörését jelezte 1988-89-ben és kisebb csúcsokat 1997-ben és 2001-ben. A betegség időbeni és térbeni eloszlását az I. szint adatainak felhasználásával állapítottuk meg. A különböző adatsorok felhasználhatóságát összehasonlítottuk.

erdők egészségi állapotfelvétele / nemzeti erdőleltár / erdőbetegségek / *Pinus sylvestris*/ *Gremmeniella abietina*

1 INTRODUCTION

The forest environments are changing rapidly. Concern about large-scale decline in forest vitality in central Europe in the late 1970's and early 1980's led Finland, as many other European countries, to initiate an extensive national survey of forest condition. The changes in forestry practices and the climate change in particular, can potentially increase the

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preconditions for biotic diseases. The changes may be expressed as the modifications in the frequencies of known pathogens, as changes in their host spectrum, but also as introduction of completely new pathogens.

However, the literature on the effects of global warming on forest diseases, for instance, is relatively scarce (see Boland et al. 2004, Garrett et al. 2006).

These factors set a need for comprehensive, systematical and statistically representative monitoring of forest condition, including biotic diseases. In some cases, the rapid deterioration in the vitality of forests has been attributed to abiotic or biotic damage (Innes and Schwyzer 1994, Keane et al. 1989). A large-scale increase in defoliation occurred in many parts of Europe after the severe drought in 2003 (see Fischer et al. 2005, for instance). It has even been proposed that the condition of trees merely reflects the fluctuating effects of biotic or abiotic agents or site conditions (Skelly and Innes 1994).

The area of forest land in Finland is over 20 million hectares. The Finnish National Forest Inventory (NFI) has produced information on forest resources over this area for more than 70 years. The first inventory dates back to 1921-1924. Different forms of damage in statistically representative samples have been registered since the 7th inventory (1977-1984). In the 7th NFI, however, the only identified causes of damage were wind, snow, moose (*Alces alces* L.) and pine- twisting rust (*Melampsora pinitorqua* (Braun) Rostr.). The Eighth NFI (1986-1994) was the first to include more detailed information on health of forests, including diseases and pests. The Ninth NFI started in 1996. Satellite images and digital maps have been routinely exploited since the Eight NFI, to produce up-to-date information of forests, and for smaller areas than before. The main aim of the first NFIs of Finland has been to estimate the volume and growth of growing stock and the cutting potential. Other aims, like forest health, multiple use of forests and biodiversity have become more and more important in the recent inventories.

A network of 3009 permanent sample plots was established in the 8th NFI in 1985-86, covering the whole country systematically. A systematic subsample of this network (see below) has been used for forest health monitoring since 1985. This subsample has been a part of a large-scale, extensive level I monitoring network covering the whole of Europe.

Gremmeniella abietina (Lagerb.) Morelet var. abietina is the causative agent of Scleroderris. canker on coniferous trees. In southern Finland, it is the most common fungal disease in forests dominated by Scots pine *(Pinus sylvestris* L.). The disease is epidemic in nature. An epidemic requires that the host trees, here Scots pines, are predisposed. If the trees are of local origin, meteorological factors and site conditions determine the degree of predisposition. Epidemics are often said to be common after cold and rainy growing seasons (Aalto-Kallonen - Kurkela 1985, Uotila 1988). Frost damage is an important cause for the differences in susceptibility (Dietrichson 1968). The susceptibility of pines is increased in shaded or dense stands (Read 1968, Niemelä et al. 1992, Nevalainen 1999). It has even been proposed that air pollution can be one of the factors that promotes the disease (Bragg – Manion 1984).

The purpose of this paper was to describe the spatial and temporal variation in the occurrence of the disease caused by *Gremmeniella abietina*, based on nationwide monitoring.

2 MATERIAL AND METHODS

This study utilized forest damage data from tree different sources a) permanent plots of the 8th National Forest Inventory , from the years 1990 and 1995 (standwise damage assessments) b) data from forest health monitoring plots (Forest Focus Level I plots (treewise assessments) and c) temporary plots of the 8th and 9th National Forest Inventories (stand damage data).

In permanent plots of the 8th NFI the sampling units were four-plot clusters in a 16 x 16 km grid with a 400-m distance between fixed- sized circle plots (0,1-0,3 ha each) in southern Finland, and three plot clusters in a 32 x 24 km grid in northern Finland (plots 600 m apart). These plots have been measured three times, 1985/86, 1990 and 1995. Unfortunately *Gremmeniella* was not recorded as a causal agent in 1985.The damage recording system was similar than in forest health surveys (see below).

A systematic subsample was taken from the permanent plots of the 8th NFI, e.g. the first plot of the tract in mineral soils was chosen, rejecting every tenth tract. These plots were used in national forest health monitoring (1986 onwards) for annual assessment of forest vitality (defoliation, discolouration) and biotic and abiotic injuries. All the dominant or co-dominant coniferous or birch trees were used as sample trees. The present network includes 499 sample plots on mineral soil and 110 on peatland. The number of Scots pine observation trees has ranged from 2002 (in 1990) trees to 6450 trees (in 2005) (for details, see Lindgren et al. 2006). In the forest health monitoring, a national system for describing the 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 forest health survey can be found e.g. in Nevalainen (1999). After 2004, the ICP-Forests manual of damage causes (Assessment of …) (referred to as the Biotic manual) has been adopted in Finland. Climatic data for these plots was produced with the models of Ojansuu and Henttonen (1983).

The sampling units of the normal NFI were temporary sample plots located systematically in clusters. Survey designs have been somewhat variable in different inventories and in different parts of the country. The distance between tracts increases from south to north, and is 7 x 7 km in southern and mid- Finland in the Ninth NFI. The tracts comprise of 14-18 relascope plots, with a 250- or 300- m distance between plots. The stand in which the centre point of the field plot was located is referred to as the centre-point stand. The area that one plot (actually, a centre point) theoretically represented, varied from 266 to 6726 hectares in the 8th NFI, and from 135 to 2285 hectares in the 9th NFI . The recent NFIs of Finland have been regional inventories, i.e. the field work has been done district wise. About 150 variables were assessed or measured in the 8th and 9th NFI at the stand, tally tree or sample tree levels. The field inventory also contained data on forest injuries, e.g. damage symptoms, their causes and apparent severities (degrees of damage), as well as an estimation of the time of the damage. Only standwise damage data from these two NFIs was used in this study. Damage has been recorded similarly, in principle, than in the permanent plots and in the forest health monitoring. Codes for registering damage symptoms, degrees of damage and causal agents of damage in the 8th NFI can be found in Nevalainen 1999 b). The description of the damaging agents was somewhat more detailed in the 9th NFI. 30 codes were used for causal agents. Moreover, two causes, instead of one, could be recorded for each stand. The codes for the degree of damage at the stand level were 0) slight damage, symptoms observed, but the damage does not reduce the silvicultural quality of the stand 1) moderate, the silvicultural quality of the stand is reduced by one class 2) severe, the stand quality is reduced by more than one class 3) complete, artificial regeneration is required. More information of the 9th NFI, for instance, can be found at http://www.metla.fi/ohjelma/vmi/vmi-historia-en.htm.

3 RESULTS

3.1 The permanent plots of the 8th NFI (1990 and 1995)

The overall occurrence if the disease had slightly decreased on the permanent plots of the 8th NFI from 1990 to 1995 (from 8.4 % to 5.6 % of Scots-pine dominated stands, respectively). A great portion of the slight damage observed in1990 was not recorded anymore in the very same plots in 1995. The disease was not re-recorded in 128 stands (*Table 1*). Most of such stands (84) were mineral soil plots. In 75 plots the disease had increased between the two dates. These changes were not spatially clustered in any part of the country, however. The lambda statistics indicates that knowing the presence of the disease in 1990 did not help in predicting the presence of the disease in 1995.

Table 1. *The occurrence of Gremmeniella in Scots-pine dominated permanent plots of the 8th NFI in 1990 and 1995.*

		Number of pine-dominated stands In 1995		
		Absent	Present	Total
In 1990	Absent	1627	75	1702
	Present	128	33	**161**
	Total	1755	**108**	**1863**

Pearson Chi-Square = 69.731 p= 0,000
Lambda (Ga 1995 dependent) = 0,000

3.2 The forest health monitoring data (1985-2005)

The proportion of symptomless trees increased rather than decreased during the 21-year period (1985-2005). As a grand mean, fungal damage occurred in 10,4 % of the Scots pine observation trees during this period (*Table 2*). The proportion of the trees infected with Gremmeniella was 8,2 % over the whole period. Most of the damage to the observation trees was slight, i.e. did not affect the vitality of the trees.

Table 2. *The mean incidence of causal agent groups in the sample trees on the Level I plots in Finland during 1985-2005. The group 'other' mostly consists of competition.*

Causal agent group	% of trees			
	Scots pine	Norway spruce	Broadleaves	Total
No damage	58.3	58.0	58.9	58.3
Game and grazing	.8	.1	1.5	.7
Insects	10.3	.3	4.4	6.3
Fungi	10.4	9.5	7.3	9.6
Abiotic	3.6	7.8	6.5	5.3
Direct action of man	1.8	3.3	2.1	2.3
Other	11.5	12.5	13.1	12.1
Unknown	3.4	8.6	6.2	5.5
Total %	100.0	100.0	100.0	100.0
Number of trees	76527	45238	22114	143879

However, there were considerable changes in the occurrence of the agent groups and specified agents over the years. The most notable of the changes was a heavy outbreak of *Gremmeniella* observed in 1988-89. Smaller peaks were observed in 1997 and 2001 (*Figure 1*). Apart from competition, *Gremmeniella* was the most important identified factors that had increased needle loss (defoliation) in Scots pine. Coarse temporal patterns of the most common causes of damage, including *Gremmeniella*, were obtained on the basis of the annual Level I data (*Figure 2*).

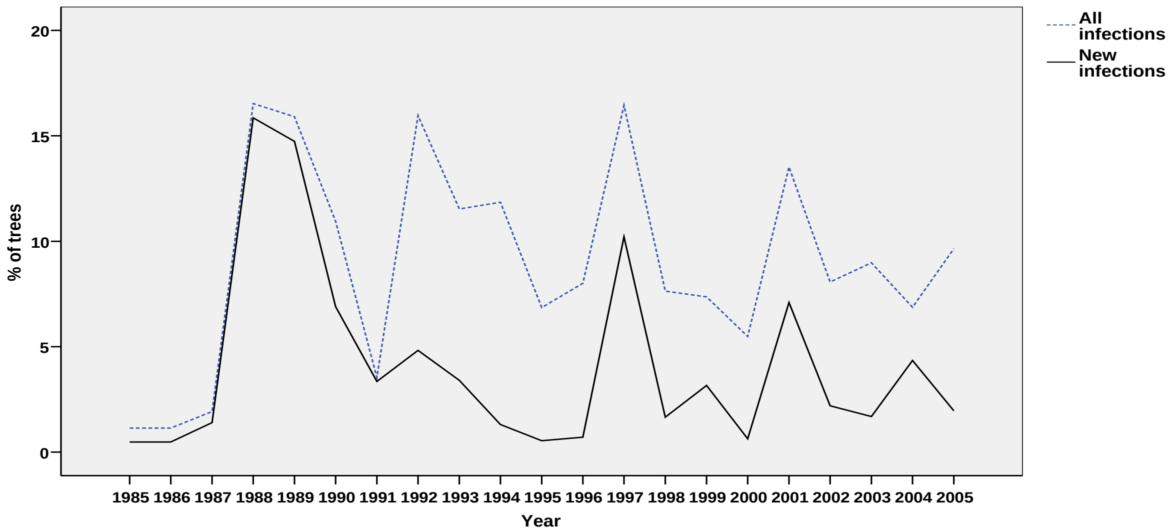


Figure 1. The annual occurrence of Gremmeniella abietina infection in Scots pine trees on the Level I plots in Finland. All and new infections are shown.

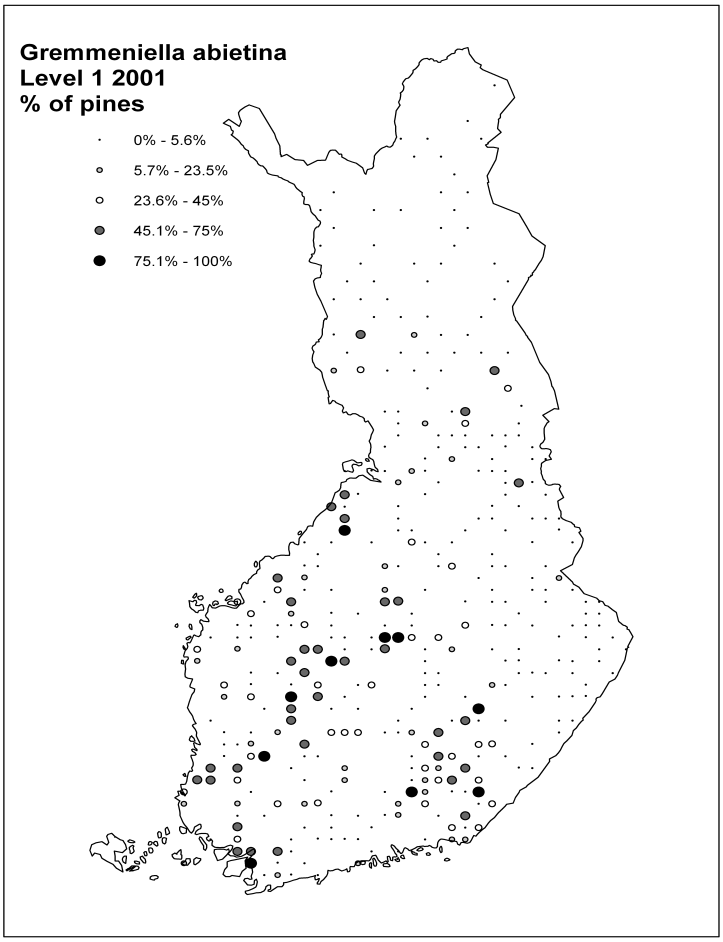
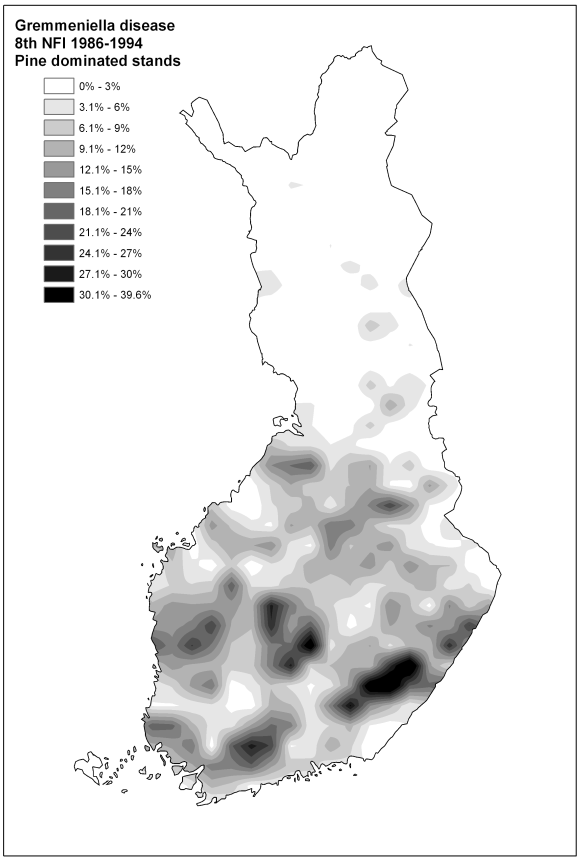


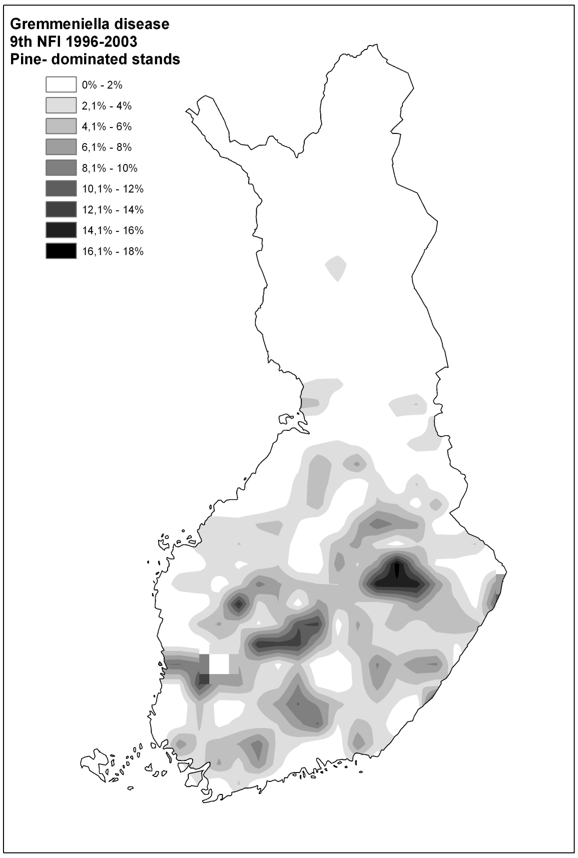
Figure 2. Example of the spatial (point) distributions of biotic damage on the Level I plots in Finland.: Gremmeniella abietina damage in 2001. The size and shading of the points shows the incidence of the disease (% of the pine trees in the plot).

It proved very difficult to model the changes in the disease occurrence in this data. In the regression models, in which two or more weather-variables explained the annual changes of the disease, the coefficients of the models were not coherent in differed parts of the country or on different years. For instance, the epidemics of 1988-89 were preceded by a rainy summer. This was however not true for the other peak years. One reason for the failure in modelling was that the annual changes were small on the average compared with the differences between the sample plots and to the number of the sample plots. The weather variables also correlated with each other. In the within years analysis, multiple regression models explained at most 10% of the differences between the changes of the disease of the sample plots in one year. Most of the weather variables were significant at least once, but the estimates of the effects were not coherent in different years. The same was true with modelling attempts using recursive partitioning or decision tree techniques (CART software): most of the variables were significant at least in some years, but the final decision tree was very complex containing 56 terminal nodes.

3.3 8th and 9th National Forest Inventories (1986-1994 and 1996-2003)

The National Forest Inventories showed that the disease was far more common in southern than in the northern parts of the country. The disease was also clearly spatially clustered (*Figure 3*).





A: B.

Figure 3. The spatial occurrence of Gremmeniella abietina in pine dominated plots in
A) 8th National Forest Inventory 1986-1992 and
B) B) 9th National Forest Inventory 1996-2003.

Maps were produced by kriging in ArcGis Spatial Analyst.

Most of the *Gremmeniella* damage observed in the NFIs was slight, i.e. did not decrease the silvicultural quality of the stand. The estimated area of Scots-pine dominated stands infected by *Gremmeniella* diminished in the 9th NFI (1996-2003) as compared to 8th NFI (1986- 1994. The proportion of diseased stands decreased from 6,8 % to 2,6 %, respectively. The diseased area had decreased by 4946 km^2. The standard errors of the estimated area infected by the disease and disease degrees were computed for the 9th NFI with the method presented by Matern (1960) (see also Ranneby 1981) (*Table 3*). Assuming that the sampling error is similar in the 8th NFI, the statistical significance and confidence intervals for the change in the estimated area between two inventories can be estimated. In the case of independent samples, the standard error of the change is $\sqrt{(s1^2+s2^2)}$, where s1 and s2 are the standard errors in the two inventories, respectively. The t- values were computed by dividing the difference in the area estimation with the standard error of change. All the p- values obtained for the change were all very significant, except for the disease degree 'complete' (*Table 4*).

Table 3. The occurrence of Gremmeniella abietina in two National Inventories (NFI's). N= number of pine-dominated plots, %= estimated percentage of pine-dominated stands, km^2 =estimated area of diseased stands.

Part of the country	Degree of *Gremmeniella* damage	8th NFI 1986-1994		9th NFI 1996-2004	
		%	km^2	%	km^2
Southern Finland	Slight	7,9	5178	3,9	2436
	Moderate	2,3	1538	1,0	612
	Severe	,2	138	,1	60
	Complete	,00	7	,0	9
	All damage	10,5	6881	4,9	3116
Northern Finland	Slight	2,0	1306	,6	446
	Moderate	,8	517	,3	236
	Severe	,1	66	,0	25
	Complete	0,0	0	,0	0
	All damage	2,9	1888	1,0	707
Whole country	Slight	5,0	6483	2,2	2882
	Moderate	1,6	2055	0,6	848
	Severe	,2	204	,1	84
	Complete	,0	27	,0	9
	All damage	6,8	8769	2,9	3823
Number of pine-dominated plots		37 243		39 049	

Table 4. Change in the estimated area of disease degrees in different parts of Finland, the sampling error and its statistical significange.

Part of the country	Disease degree	Change in the estimated area, km²	Sampling error in 9th NFI	t- value	Significance of the change
Southern Finland	Slight	2742	94	20,628	,000
	Moderate	926	47	13,932	,000
	Severe	78	12	4,618	,000
	Complete	18	7	1,778	,075
	All damage	3765	109	24,426	,000
Northern Finland	Slight	859	47	12,924	,000
	Moderate	281	39	5,096	,000
	Severe	401	12	2,409	,016
	Complete	0	-	,000	,500
	All damage	1181	70	11,930	,000
Whole country	Slight	3601	61	41,746	,000
	Moderate	1207	105	8,129	,000
	Severe	120	17	5,002	,000
	Complete	18	7	1,778	,075
	All damage	4946	130	26,904	,000

Compared with level I data, it was evident, for instance, that the *Gremmeniella* epidemics in 1988-89 and 2001, was partly missed by NFI surveys, due to the fact that the inventory was being carried out in different parts of the country during the worst years.

4 DISCUSSION

The three sources of data used in this study complement each other quite well. The two yet unanswered questions for the research in future could be: Why the disease is more common in some years then in the others?. Why some stands are more susceptible than the others? This study at least failed to prove the assumption that epidemics usually begin after cold and rainy growing seasons (see Uotila 1988, for instance). The other question will be studied by applying risk models.

The weaknesses in the NFI- data can related to sampling error and detection error, in other words: i) spatial representativeness of field plots ii) reliability of the field survey, including observers ability to identify the causes and iii) epidemic nature of some damage. Identification of the causal agent is not an easy task in NFI field data collection because most of the damages are already old at the time of the observation and field work is done throughout the field season. The proportion of unidentified damage has remained at about the same level since the 8th NFI (see Yli-Kojola – Nevalainen 2006).

The field team leaders could reliably distinguish at least injuries caused by *Gremmeniella abietina* from other symptoms (Nevalainen 1999), but on the other hand, in the routine inventory slight infections are easily overlooked. However, the most important stand damage (in the economic sense) are recorded reliably in the routine NFI's.

National Forest Inventories are statistically representative samples of Finland's forests. The NFIs of Finland (before 2004) were regional inventories, i.e. the field work was carried out districtwise. The design of the 10th NFI, which started in 2004, was changed into a continuous inventory, i.e. field plots are measured throughout the whole country each year, and results at the nation level can therefore be achieved annually or bi-annually. Also, a new network of permanent plots was established during the 9th NFI: every fourth cluster is marked as permanent, and these permanent plots will be reassessed in the 10th NFI.

The Level I network is not a representative sample of the forests in Finland, due to the rather sparse network (especially in northern Finland), as well as to the fact that the sample is restricted to dominant and co-dominant trees. The Level I network provides an annual picture of large-scale trends in crown condition (defoliation, discoloration, abiotic and biotic damage) at the European level. It also offers the possibility to investigate relationships between stress factors and forest condition. Although the most widespread epidemics are revealed in the level I network (seealso e.g. Nevalainen – Heinonen 2000), the forest health monitoring data is not suitable for the monitoring of the changes in the frequency of individual causes. There are also other sources of information of forest damage, such as questionnaires and voluntary reports among foresters and forest owners, but the results are very general. Therefore, despite of its shortcomings, the national forest inventory is the only statistically representative and extensive way to monitor the changes in the forest health in Finland.

In the future, a system for evaluation monitoring (see Smith et al. 2004, for instance) is urgently needed. When major changes or trends in forest health are detected, the extent, severity, and causes of undesirable changes should be determined, associations between forest health and forest stress indicators should be identified, and management consequences and alternatives for reducing the effects of forest stress should be defined.

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