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ANNE SAIRANEN

SITE CHARACTERISTICS OF SCOTS PINE STANDS INFECTED BY *GREMMENIELLA ABIETINA* IN CENTRAL FINLAND. I: MINERAL SOIL SITES

VERSOSURMAN VAIVAAMIEN MÄNNIKÖITTEN KASVUPAIKKAOMINAISUUDET KESKI-SUOMESSA. I: KIVENNÄISMAAT

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The Society of Forestry in Finland
Suomen Metsätieteellinen Seura r.y.
Unioninkatu 40 B, 00170 Helsinki
Tel. +358-0-658 707 Fax: +358-0-1917 619
Telex: 125181 hyfor sf

The Finnish Forest Research Institute
Metsäntutkimuslaitos
Unioninkatu 40 A, 00170 Helsinki
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SITE CHARACTERISTICS OF SCOTS PINE STANDS INFECTED BY *GREMMENIELLA ABIETINA* IN CENTRAL FINLAND.
I: MINERAL SOIL SITES

Versosurman vaivaamien männiköitten kasvupaikkaominaisuudet Keski-Suomessa.
I: Kivennäismaat

Anne Sairanen

Approved on 26.10.1990

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Mineral soil sites where Scots pines (*Pinus sylvestris*) were suffering from *Gremmeniella abietina* die-back were characterized and classified in Central Finland. The tree stand, ground vegetation, soil type and site topography were described on 163 sample plots in 16 stands. The sites were classified according to the Cajander forest classification system and also numerically, using TWINSPAN analysis based on the ground vegetation. The site topography of severely damaged stands was checked from colour infrared aerial photographs. The disease was most severe in depressions and frost pockets. Apart from topography no significant correlations were found between disease severity and site factors. No typical vegetational pattern or forest site type of the severely affected stands could by detected. Most of the stands were growing on medium-coarse, unfertile soil with a rather thick humus layer.

Työssä tutkittiin versosurmasta (*Gremmeniella abietina*) kärsivien kivennäismaiden männiköiden kasvupaikkaominaisuuksia Keski-Suomessa. Puusto, pintakasvillisuus, maaperä ja topografia tutkittiin 16 metsiköstä yhteensä 163 koealalta. Kasvupaikat luokiteltiin Cajanderin metsätyyppijärjestelmän mukaan ja pintakasvillisuudesta tehdyllä numeerisella TWINSPAN-analyysillä. Vakavasti vaurioituneiden metsikkökuvioiden sijainti tarkastettiin väri-infrapuna-ilmakuvilta. Vakavat tuhot keskittyivät notkelmien pohjille ja laaksojen alaville tasanteille. Muiden kasvupaikkaominaisuuksien ei voitu osoittaa lisäävän tuhoja. Kasvillisuuden perusteella ei voitu tunnistaa tyypillistä, tuhoille altista kasvupaikkaa. Useimmat tutkitut metsiköt kasvoivat keskikarkeilla, karuilla mailla, joilla oli paksu kangashumuskerros.

Keywords: *Gremmeniella abietina, Ascocalyx abietina*, damage risk, site classification, Scots pine.
ODC 443.3 + 174.7 *Pinus sylvestris* + 114

Author's address: The Finnish Forest Research Institute, Department of Forest Protection, P.O. Box 18, SF-01301 Vantaa, Finland.

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Contents

1. Introduction

There have been serious epidemics of Scleroderris canker in Southern and Central Finland during the late 1970's and early 1980's (Kurkela 1981, Aalto-Kallonen & Kurkela 1985, Uotila 1988). The disease has been the most severe in the relatively high watershed area of Suomenselkä, especially in pine plantations approaching their first commercial thinning (Kallio et al. 1985).

Pine stands regenerated with introduced southern provenances were initially attacked. The epidemic spread to native pine stands of local origin during the successive cool and rainy growing seasons beginning in 1974 (Kurkela 1984). The most severe damage has occurred in narrow river basins, kettle holes and on drained peatland areas (Aalto-Kallonen and Kurkela 1985, Kallio et al. 1985, Uotila 1988). In Central and Western Europe dense stands have also been more susceptible than sparse stands (Read 1967, Gremmen 1972, Donaubauer 1974).

Scleroderris canker is caused by a fungus, *Gremmeniella abietina* (Lagerb.) Morelet (= *Ascocalyx abietina* (Lagerb.) Schläpfer-Bernhard, = *Scleroderris lagerbergii* Gremmen). It can successfully infect only trees predisposed by environmental stress factors (Read 1967, Donaubauer 1972). All factors responsible for retarded maturing of the shoots decrease the resistance and increase the susceptibility to *Gremmeniella abietina* (Dietrichson 1968, Donaubauer 1972).

The maturing process can be delayed by cool, cloudy and rainy summer weather (Venn 1970, Norokorpi 1972, Uotila 1988), a cool, moist and shady microclimate (Read 1968, Donaubauer 1974, Uotila 1988), summer frosts (Dietrichson 1968), and the vigorous height growth resulting from the use of southern provenances of pine or high soil fertility (Dietrichson 1968, Venn 1970, Pätilä 1984, Vasander & Lindholm 1985). Direct frost injuries may provide an infection route for the fungus (Roll-Hansen 1967, Pomerleau 1971).

The unfavourable microclimate of kettle holes, depressions and low-lying peatland areas is supposed to be the main reason for the high disease frequency encountered on such sites (Aalto-Kallonen & Kurkela 1985, Uotila 1988). In hilly terrain the climate becomes cooler with increasing altitude. During clear nights, however, the situation is locally reversed since the descending cold air is trapped in depressions and valley bottoms (Elomaa 1976, Rajakorpi 1984). High soil fertility or poor oxygen conditions may increase the susceptibility (Kurkela 1984, Lähde 1974). A major part of Southern Finland was covered by sea after the last glaciation period and the finest mineral soil material has accumulated in the lowest lying parts of the terrain (Sauramo 1940).

The aim of this study is to characterize the sites in Central Finland where Scots pine (*Pinus sylvestris* L.) was found to be suffering from Scleroderris canker. The relationships between damage degree, topography, vegetation, forest site type and soil are investigated. Questions of special concern are: Are all heavily damaged stands located in depressions, is the site more fertile, the soil finer textured and the trees more densely stocked in severely affected stands than in healthy or slightly damaged stands, and is the soil temporarily water-logged? It is important in forestry to recognize and delimit sites where tree species other than pine should be used owing to the potential risk of attack by *Gremmeniella* on pine.

I wish to thank Prof. Timo Kurkela for his advice and encouragement, and Mr. Antti Uotila, Dr. Pekka Tamminen and Mr. Mikko Kukkola for the many helpful discussions. During the field work I was assisted by Mr. Antti Manier, Mr. Veikko Siltala and Ms. Katri Pienimäki. Mr. Pentti Pienimäki offered his invaluable help in selecting the study sites at Multia. Metsä-Serla Co. and Rosenlew Co. kindly allowed their forests to be used as study areas. Mr. Pekka Alajärvi provided his study plot network and aerial photographs of Ruovesi and Juupajoki. I would also like to thank Dr. Eeva-Liisa Jukola-Sulonen and Dr. Lalli Laine, who commented on the manuscript, and Mr. John Derome, who revised the English text.

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2. Materials and methods

21. The stands

Multia, which is one of the most seriously affected areas in Central Finland, was chosen as the main study area. In addition to Multia, some earlier studies have also been carried out on Scleroderris canker at Juupajoki, Kuru and Ruovesi, about 100 km to the south (Aalto-Kallonen & Kurkela 1985, Alajärvi 1987, Antti Uotila, University of Helsinki, Forestry Field Station, SF-35500 Korkeakoski, unpubl.). The stands from these projects which contained severely damaged areas were included in the study (Fig. 1). Multia is situated in the upland area of the Suomenselkä watershed. Kuru lies at the southern end of the watershed, and Juupajoki and Ruovesi somewhat to the southeast of it. The Scleroderris canker epidemic started in the area in the mid 1970's. The worst damage occurred in 1975, 1978, 1982 and 1985 (Uotila 1988). In summer 1988 many cases of infection were again observed on the lower branches of pines.

The individual stands at Multia were chosen subjectively to represent the variation in topography and soil quality of the affected localities. The sample plots at Juupajoki, Ruovesi and Kuru had been established, and stand characteristics including disease intensity recorded in 1983, 1985 and 1986. The remaining field work was carried out in autumn 1986 and summer 1987. The vegetation was surveyed in July and August 1987. All the investigated stands were at the pole stage or young thinning stage. Most of the stands had been regenerated by sowing burned-over areas with pine seed. The age of the stands ranged from 20 to 40 years, the dominant height from 5 to 14 m and the basal area from 3 to 30 m^2/ha. Pine accounted for an average of 94 % of the basal area. The stand density varied between 300 and 3700 stems per hectar. At Multia the stumps of trees felled after the onset of the epidemic were included in the stem number. A total of 16 stands and 163 sample plots were described. In addition, the particle size distribution of the soil was determined in three clearcut damage areas investigated by Aalto-Kallonen & Kurkela (1985).

Colour infrared aerial photography was used to obtain an overview of the location of severely damaged stands. At Multia an area of 8000 hectars was photographed in August 1987. At Ruovesi and Juupajoki two separate areas totalling 6000 hectars were photographed in the summers of 1985 and 1986 (Alajärvi 1987). The photographs were taken at a scale of 1:8000, and viewed with a magnifying stereoscope.

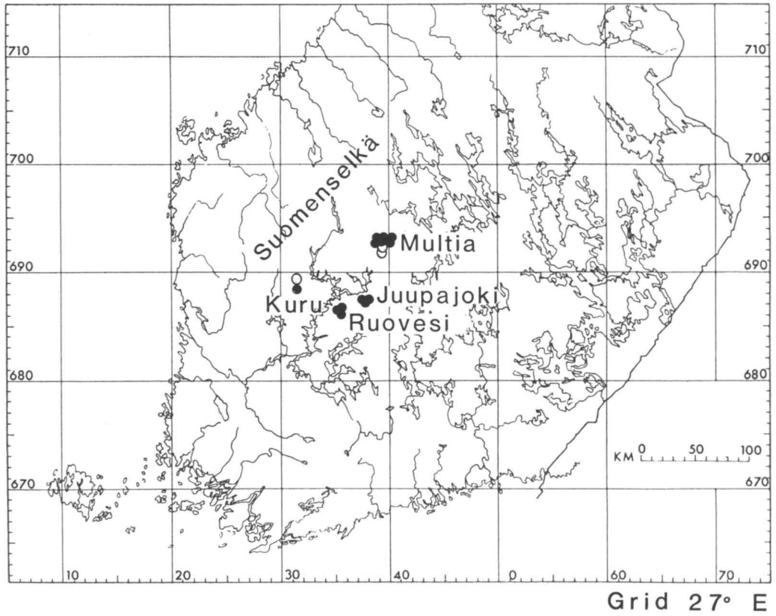


Fig 1. Location of the stands (●) and clearcut areas (○). Coordinates of the uniform grid system (Grid 27° E) are marked on the map (Heikinheimo & Raatikainen 1971).
Kuva 1. Tutkittujen metsiköitten (●) ja avohakkuualueiden (○) sijainti. Kartalle on merkitty yhtenäiskoordinaatisto, Grid 27° E (Heikinheimo & Raatikainen 1971).

22. Methods

Sample plots

Circular sample plots were marked out in the diseased stands at regular intervals along a gradient line according to the damage degree. The first sample plots were placed in the part of the stand most severely damaged, and the last in an apparently healthy part of the stand. The size of the sample plots was 100 or 200 m^2 depending on the density of the stand.

Stand measurements

The tree species and breast height diameter of every tree were recorded, and the pines were classified into 5 damage classes. The number and tree species composition of the stumps were noted if the stand had been thinned after the onset of the epidemic. 5 to 10 pines per sample plot were chosen systematically as sample trees. The height and lower limit of the living crown of the sample trees were measured, and the age determined on the basis of the number of branch whorls.

Estimation of disease intensity

At Juupajoki, Ruovesi and Kuru the disease intensity was estimated as the percentage of infected shoots in the crown (Uotila 1985). This is easy to do as long as the brown needles remain on the trees. At the time the field work was done at Multia, however, most of the needles had fallen and hence the pines were classified into damage classes.

The damage classes were designed to express the ability of pines to survive and continue to grow. According to Vuokila (1968), a pine crown can be pruned to 40 % of the total length of the tree without any increment loss. Another criterion used in the classification was the presence or absence of a living leader shoot.

Damage classes were defined as follows:

1. The proportion of the living crown is more than 40 % of the total length of the tree, and the leader shoot is healthy.
2. The proportion of the living crown is 30 — 40 % of the total length of the tree, and the leader shoot is healthy.
3. The proportion of the living crown is less than 30 % of the total length of the tree and the tree has a living leader shoot. A lateral branch may have replaced a dead leader shoot.
4. The tree has no living leader shoot.
5. Dead tree.

Trees belonging to the first two damage classes were considered as capable of recovery. The percentage limit between the first and the second damage class should have been higher, because *Gremmeniella abietina* also kills shoots inside the crown and the stem cankers decrease growth (Aalto-Kallonen & Kurkela 1985, Riihinen 1989). Trees belonging to the third class may recover if the following growing seasons are favourable. Recovery of the trees in the fourth class is unlikely, because replacement of the leader shoot had not occurred even though two favourable summers had passed since the last epidemic.

Vegetation

The vegetation was described on four 1 m^2 quadrats on each circular sample plot. The coverage of all shrub, field and bottom layer species was estimated using a nine-class coverage scale (Pakarinen 1984). The abundancy of plant species on the plot, but outside the sample quadrats was recorded as one. The mean coverage of different plant species on each circular sample plot was calculated using the geometrical mean of the class limits as class center (Oksanen 1976). Nomenclature of the plant species is according to Hämet-Ahti et al. (1986), Koponen et al. (1977) and Santesson (1984). The forest site type was determined according to Cajander (1926) and Kalela (1952).

Soil

The soil profile was described and humus and mineral soil samples taken at three points on each circular sample plot. Mineral soil was sampled between a depth of 5 to 25 cm. The pH of the humus was determined from a 1:2.5 (v/v) soil-water slurry after standing for 24 hours. The particle size distribution of the mineral soil samples was determined from the stone-free fraction (less than 20 mm) by dry sieving using sieves with a mesh size of 20, 2, 0.6, 0.2 and 0.06 mm. Silt and clay fractions were removed by washing the weighted samples over the finest sieve before dry sieving. The presence of silt and clay was estimated in the field by rolling the soil between the palms of the hands (Aaltonen 1941b). The soil type was determined according to Aaltonen et al. (1949) and Virkkala (1969).

Site fertility

The estimation of site fertility was based on the ground vegetation. Existing knowledge of the site requirements of different plant species was used in the ecological interpretation of the ordination and classification analyses (Kujala 1926a, 1926b, 1926c). The number of plant species on a site increases with fertility (Kuusipalo 1983, 1984), and the number of herbs and grasses is greater in the more fertile forest site types (e.g. Cajander 1926). The proportion of fine fractions in the uppermost mineral soil layer (particles finer than 0.06 mm) and the pH of the humus layer are correlated with the nutrient contents of the soil (Urvas & Erviö 1974, Sepponen 1981). Stones and a deep eluviation horizon decrease the fertility (Aaltonen 1941a, Viro 1947). Site classification based on height over age of the dominant tree stand (Gustavsen 1980, Vuokila & Väliaho 1980) could not be used in the estimation of productive capacity, because the method is reliable only in uniform monocultures which are over 40 years of age and do not suffer from any increment losses due to pests or disease (Kuusela 1982, Varmola 1987).

Topography

The aspect and gradient of the site were measured. Since these factors have an interactive effect on the microclimatical conditions, a joint variable (WARM) was constructed by combining them (Kuusipalo 1985). This variable has minimum values on steep NE slopes, maximum values on steep SW slopes, and intermediate values for the various combinations of steepness and aspect lying between the two extremes. The altitude was checked from topographic maps (1:20 000, National Board of Survey) and the elevation from the bottom of the nearest cold air drainage basin was recorded. Severely affected stands were outlined on the infrared aerial photographs. These boundaries were later transferred to topographic maps with contour lines. Circular sample plots that had been measured in the field were used as references in the interpretation of disease intensity from the aerial photographs.

23. Data analysis

The data were analysed in two sets because of the differences between the disease intensity estimations. The proportion of non-recoverable trees (damage classes 3-5) on a sample plot was used as a continuous variable of the disease intensity in the data collected at Multia. The disease intensity was also estimated as damage classes in one stand at Juupajoki, and this stand is analysed together with the data from Multia. In the data collected from Juupajoki, Kuru and Ruovesi the average disease intensity of a sample plot was calculated as the mean of the disease intensities of the single trees. The former set of data is referred to as the 'Multia data' later on in the text, and the latter as the 'Ruovesi data'. The Multia data include 79 sample plots at Multia and 12 at Juupajoki, and the Ruovesi data 31 sample plots at Kuru and 41 sample plots at Juupajoki and Ruovesi.

The vegetation data were analyzed in one unit using detrended correspondence analysis (DECORANA) as the ordination method, and two-way indicator species analysis (TWINSPAN) as the classification method (Gauch 1982, Mikkola & Jukola-Sulonen 1984). The Shannon-Wiever diversity index (Jukola-Sulonen 1983) and the number of plant species in the field and bottom layers (Kuusipalo 1983) were used as measures of species diversity.

The relationship between disease intensity and the environmental characteristics was investigated graphically and with parametric and non-parametric correlation tests. The analyses were performed on the stand, area and data set levels. The results for the stand and area level are discussed if they differ from the results for the data set level. The sample plots were combined in two groups in order to characterize the sites with a high risk of *Gremmeniella* infection on the pines. In the Multia data, plots where the number of recoverable trees was at least 50 % of the targeted growing stock, were considered recoverable, and the rest as being severely damaged (Takala 1986). In the Ruovesi data, sample plots with an average disease intensity of less than 45 % were considered recoverable, and those with a disease intensity of 45 % or more, severely damaged.

The environmental differences between the two groups (recoverable plots and severely damaged plots) were tested with Students t-test, Mann-Whitney's u-test, Kruskal-Wallis test or parametrical analysis of variance (BMDP statistical ... 1988).

Of the stand characteristics, the effect of stand density, and breast height diameter on the disease intensity were investigated. The data were not suitable for analysing the effect of tree species composition, because most of the stands were pine monocultures.

3. Results

31. Vegetation and forest site types

The sample plots and plant species were organized, using DECORANA ordination analysis, on two axes based on the species coverages (Figs. 2—3). Plant species with a frequency of less than 5 % in the whole material were excluded, as well as twelve plots that had been fertilized one year before.

In the ordination plot the fertility and moisture gradients appeared to form an oblique angle with the two main axes (Fig. 2). The more demanding herbs and grasses were placed down on the left, indicators of paludification down on the right, and species of dry-and-poor sites up in the middle. Spearman's rank correlation test was used to study the relationship between soil parameters and the eigenvalues of the sample plots on the two axes. The total coverage of *Sphagnum* spp. and the thickness of the humus layer best correlated with the eigenvalues on the first (vertical) axis (Table 1). In addition to these, measures of fertility (humus pH, species number and species diversity), correlated with the eigenvalues on the second (horizontal) axis. The eigenvalue of the first axis was somewhat higher (0.321) than that of the second (0.213), which means that the amplitude of soil moisture was greater than the amplitude of soil fertility.

In order to arrange the sample plots according to soil moisture and fertility, the coordinates were orthogonally rotated 25/360° to the left. The angle that gave the best fit with the moisture and fertility gradients was visually estimated from Figure 2. According to the correlation tests, rotation

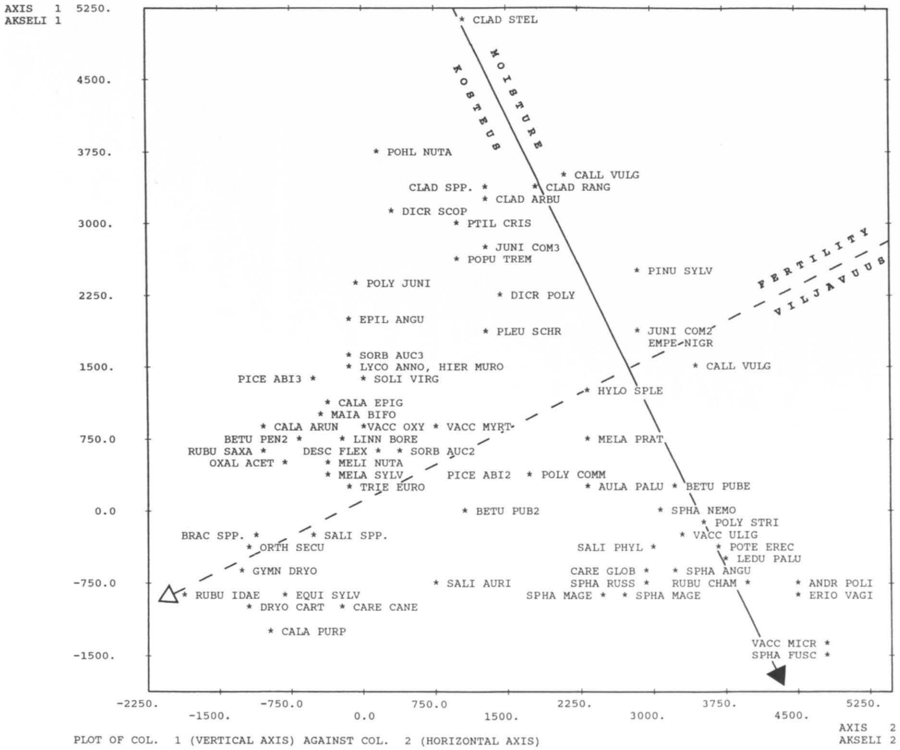


Fig. 2. DECORANA ordination of the plant species. The eigenvalues of the first and the second axis are 0.321 and 0.213. The moisture and the fertility gradient run at an angle of about 25° to the axes. See Appendix for the species abbreviations.

Kuva 2. Kasvilajien DECORANA-ordinaatio. Ensimmäisen ja toisen ordinaatioakselin ominaisarvot ovat 0.321 ja 0.213. Kosteus ja viljavuusgradientti kulkevat akseleihin nähden noin 25°:n kulmassa. Lajinimien lyhenteet liitteessä.

clearly improved the fit of the second axis with the fertility gradient (Table 1). The fit of the first axis with the moisture gradient remained the same. The disease intensity of the study plots did not correlate significantly with any of the axes (Table 1). The distribution of recovered and severely damaged sample plots in the ordination diagram did not differ much (Fig. 3). In the Multia data there were slightly more healthy plots at the dry end, and slightly more severely damaged plots at the wet end of the moisture gradient.

Soil moisture seemed to play the major role in generating the differences in vegetation between the sample plots at Multia. In the ordination diagram the Multia sample plots were scattered mainly along the moisture gradient (Fig. 3). The Juupajoki, Kuru and Ruovesi sample plots also differed from each other as regards fertility.

TWINSPAN clustering analysis was used for the phytosociological classification of the sample plots (Fig. 4). Three division levels were used because the groups became too small on the fourth level. Different forest site types could be recognized in the eight groups of the third division level. The environmental and stand characteristics of these groups are presented in Table 2, and the position in the ordination diagram in Fig. 3.

TWINSPAN separated the moist sites from the dry sites on the first division level. The moist sites were divided into paludified and non-paludified sites on the second level. A group with *Brachythecium* spp. and *Calamagrostis purpurea* (group 1) was separated from the less fertile, paludified sites (group 2) on the third level. Non-paludified moist sites were divided into a group with *Vaccinium* type (VT) vegetation (group 3) and another with *Myrtillus* type (MT) vegetation (group 4). Most of the sample plots in group three had a thick humus layer which is characteristic of the *Vaccinium-Myrtillus* type (VMT) in the water-shed areas (Kalela 1952). VMT is moister than VT and less fertile than MT (Keltikangas 1959).

The four clusters of dry sites on the third level represented *Vaccinium* and *Calluna* site types. Groups 5 to 7 belonged to the *Vaccinium* type, and group 8 to the *Calluna*

Table 1. Spearman rank correlations (rs) of environmental factors and disease intensity with original and rotated DECORANA axes. *, **, *** indicate significance of rs at the 5 %, 1 % and 0.1 % levels.

*Taulukko 1. Koealojen DECORANA-ordinaatiossa kahdella ensimmäisellä akselilla saamien ominaisarvojen Spearman-korrelaatio (rs) eri ympäristötekijöiden kanssa alkuperäisessä ja kierretyssä koordinaatistossa. *, **, *** ilmaisevat rs:n merkitsevyyden 5 %, 1 % ja 0,1 %:n tasoilla.*

		Axis—*Akseli*			
		Original *Alkuperäinen*		Rotated *Kierretty*	
		1	2	1	2
Fertility indicators *Viljavuuden indikaattorit*					
Number of plant species *Kenttäkerroksen kasvilajien lkm*	rs	—0.372 **	—0.591 ***	—0.208 *	—0.659 ***
Number of herb and grass species *Kenttäkerroksen heinä- ja ruoholajien lkm*	rs	—0.358 ***	—0.597 ***	—0.161	—0.668 ***
Shannon-Wiever index *Shannon-Wiever indeksi*	rs	—0.314 **	—0.344 **	—0.202 *	—0.437 ***
Humus pH *Humuksen pH*	rs	0.152	—0.270 *	—0.160	—0.507 ***
Thickness of A horizon *Huuhtoutumiskerroksen paksuus*	rs	0.039	0.493 ***	—0.126	0.387 ***
Proportion of fine fractions *Hienoaineksen osuus*	rs	—0.244 *	—0.189 *	—0.210 *	—0.244 *
Indicators of soil moisture *Maaperän kosteutta kuvaavat muuttujat*					
Thickness of humus layer *Humuskerroksen paksuus*	rs	—0.470 ***	0.566 ***	—0.636 ***	0.234 *
Coverage of *Sphagnum* spp. *Rahkasammalten peittävyys*	rs	—0.686 ***	0.396 ***	—0.770 ***	0.054
Topography *Topografia*					
Site elevation *Suhteellinen korkeus*	rs	0.219 *	—0.162	0.268 *	0.028
Disease intensity *Tuhoaste*					
Multia data *Multian aineisto*	rs	—0.161	0.073	—0.184	—0.033
Ruovesi data *Ruoveden aineisto*	rs	0.130	0.058	0.111	0.076
Number of sample plots *Koealojen määrä*					163

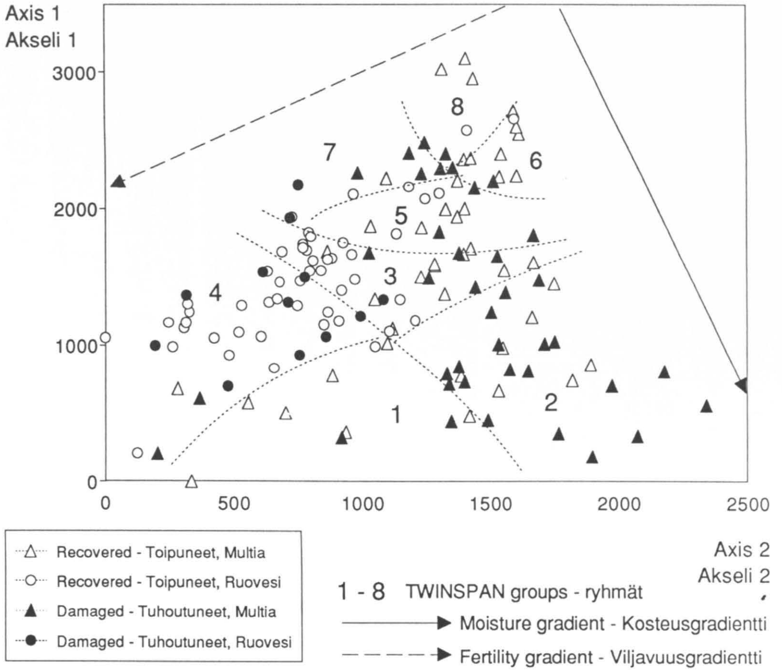


Fig. 3. The location of recoverable and severely damaged plots of the Multia and the Ruovesi data in the DECORANA ordination. The areas separated by dashed lines show the approximate location of the eight clusters produced by the TWINSPAN classification.

Kuva 3. Koealojen DECORANA-ordinaatio. Toipuneet ja tuhoutuneet alat Multian ja Ruoveden aineistossa on merkitty eri symbolein. Koealoista TWINSPAN-analyysissä muodostuneet kahdeksan ryhmää sijoittuvat ordinaatiossa suunnilleen katkoviivojen osoittamalla tavalla.

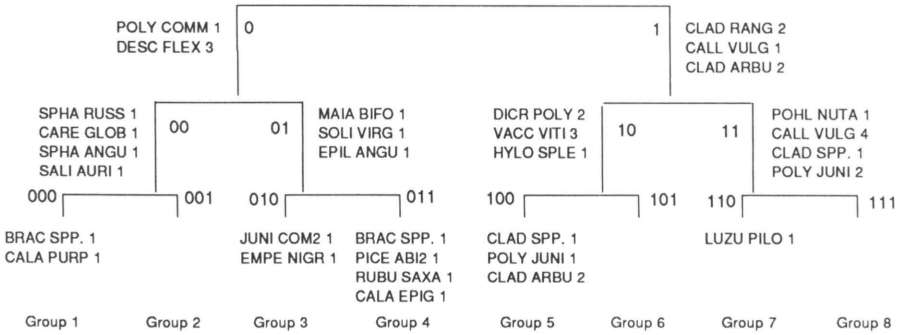


Fig. 4. TWINSPAN classification dendrogram of the vegetation data. Indicator species have been marked at the branching points. Numbers after species names point to the pseudospecies cut levels: 1 = < 2 %, 2 = 2—4.9 %, 3 = 5—9.9 %, 4 = 10—19.9 %, 5 = > 20 % coverage. See Appendix for the species abbreviations.

Kuva 4. Aluskasvillisuudesta tehdyn TWINSPAN-luokitteluanalyysin dendrogrammi. Indikaattorilajien nimien lyhenteiden jäljessä olevat numerot tarkoittavat lajin peittävyyttä: 1 = < 2 %, 2 = 2–4,9 %, 3 = 5–9,9 %, 4 = 10–19,9 %, 5 = > 20 %. Lajinimien lyhenteet liitteessä.

type. Group 7 was combined with group 8 on the second level because of the abundant *Calluna* and moss and lichen species growing on exposed mineral soil. The abundancy of *Calluna* on sample plots belonging to group 7 can be explained by the fact that a young and severely damaged stand does not shade the ground vegetation. The ecological characteristics of group 7 resembled those of group 5 (Table 2). Group 6 represented the poorest sites of the *Vaccinium* type.

The variation in topography was rather similar in all groups. The paludified plots were located a bit lower down in the depressions than the others (Table 2). The variable WARM reached its maximum values

Table 2. Characteristics of vegetation, soil and topography in sample plot clusters created by TWINSPAN clustering. X = mean, SD = standard deviation.

Taulukko 2. Kasvipeite, maaperä ja topografia TWINSPANIN muodostamissa ryhmissä. X = keskiarvo, SD = keskihajonta.

		TWINSPAN groups – *TWINSPAN-ryhmät*							
		1	2	3	4	5	6	7	8
Vegetation — *Kasvipeite*									
Stand density, trees/ha	X	1 225	1 481	1 867	2 132	1 763	1 492	1 746	1 565
Puuston runkoluku, kpl/ha	SD	464	535	513	600	517	530	460	489
Number of plant species	X	14	12	15	21	17	10	17	11
Kenttä- ja pohjakerroksen kasvilajien lkm	SD	4	3	3	4	3	3	3	2
Number of herb and grass species	X	8	5	6	10	6	2	6	1
Kenttäkerroksen heinä- ja ruoholajien lkm	SD	3	3	3	3	3	1	1	1
Shannon-Wiever index	X	1.588	1.313	1.532	1.917	1.668	1.222	1.807	1.560
Shannon-Wiever -indeksi	SD	0.567	0.296	0.359	0.448	0.256	0.254	0.325	0.365
Total coverage of *Sphagnum* spp. (%)	X	6	14	1	1	0	0	1	0
Rahkasammalten peittävyys (%)	SD	5	14	3	4	0	0	2	0
Soil — *Maaperä*									
Soil profile (%) *Maannos (%)*	Iron podsol *Rautapodsoli*	—	20	70	75	90	100	90	90
	Iron-humus p. *Rautahumusp.*	20	20	25	20	10	—	10	10
	Humus podsol *Humusp.*	80	60	5	5	—	—	—	—
Thickness of humus layer (cm)	X	11.5	13.4	5.5	3.5	2.6	5.1	4.8	4.6
Humuskerroksen paksuus (cm)	SD	2.5	5.5	2.9	2.0	1.3	1.5	2.7	1.3
Thickness of A horizon (cm)	X	10	10	9	5	9	12	8	7
Huuhtoutumiskerroksen paksuus (cm)	SD	5	4	3	3	4	4	4	3
Humus pH	X	3.93	3.85	3.90	4.02	3.90	3.80	3.99	3.65
Humuskerroksen pH	SD	0.12	0.17	0.14	0.20	0.21	0.14	0.11	0.11
Proportion of fine fractions (%)	X	42	29	27	27	23	16	26	21
Hienoaineksen osuus (%)	SD	22	10	5	11	6	7	8	13
Topography — *Topografia*									
Site elevation (m)	X	3	7	11	11	16	9	8	8
Suhteellinen korkeus (m)	SD	1	5	6	8	8	3	6	4
WARM	0	—	—	5	—	—	—	—	—
(%)	1	—	10	10	10	15	—	—	10
	2	—	5	5	5	—	25	10	—
	2.5	100	85	70	55	75	75	70	40
	3	—	—	5	15	10	—	10	10
	4	—	—	5	10	—	—	10	10
	5	—	—	—	5	—	—	—	30
Number of sample plots *Koealojen määrä*		10	25	46	26	8	14	12	10

Table 3. Mean disease intensity in the eight TWINSPAN clusters. X = mean, SD = standard deviation, N = number of sample plots.
Taulukko 3. Keskimääräinen tuhoaste eri TWINSPAN-ryhmiin kuuluvilla aloilla. X = keskiarvo, SD = keskihajonta, N = koealojen määrä.

Disease intensity (%) — *Tuhoaste (%)*		TWINSPAN groups — *TWINSPAN-ryhmät* 1	2	3	4	5	6	7	8
Multia data	X	50	51	43	56	22	26	82*	27
Multian aineisto	SD	31	36	39	15	30	23	19	33
	N	10	25	16	3	3	14	9	8
Ruovesi data	X			35	31	34		31	35
Ruoveden aineisto	SD			11	13	6		14	5
	N			30	23	5		3	2

* Significantly different at the 5 % level from groups 6 and 8 according to the Kruskal-Wallis test.
* *Kruskalin-Wallisin testin mukaan poikkeaa ryhmistä 6 ja 8 5 %:n tasolla.*

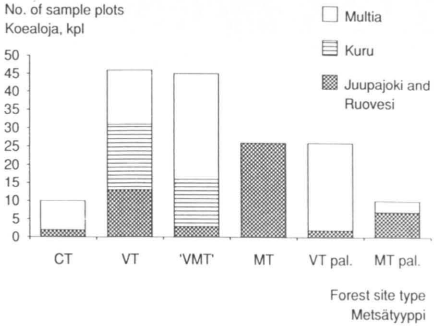


Fig. 5. Forest site type distribution of the sample plots at Multia, Kuru and in the Juupajoki-Ruovesi area. Key to symbols: CT = *Calluna* site type, VT = *Vaccinium* site type, 'VMT' = *Vaccinium* site type with thick humus layer, MT = *Myrtillus* site type, VT pal. = paludified *Vaccinium* site type, MT pal. = paludified *Myrtillus* site type.
Kuva 5. Koealojen jakautuminen eri metsätyyppeihin Multialla, Kurussa ja Juupajoen-Ruoveden alueella. CT = kanervatyyppi, VT = puolukkatyyppi, 'VMT' = paksuhumuksinen puolukkatyyppi, MT = mustikkatyyppi, VT pal. = soistunut puolukkatyyppi, MT pal. = soistunut mustikkatyyppi.

in the driest group. However, level or slightly sloping topography (WARM = 2.5) dominated in all groups.

There were no differences in average disease intensity between the groups in the Ruovesi data (Kruskal-Wallis H = 2.75, P = 0.60) (Table 3). In the Multia data the mean disease intensity was lowest on the semi-dry and dry sites (groups 5 to 8), excluding group 7. The only statistically significant differences were between group 7 and group 6, and group 7 and group 8 (5 % level). A common feature of the sites of the healthiest stands was their microclimatically favourable topography. They were situated partly on hilltops and partly on a steep, SW-facing riverbank. The seventh group included sample plots in depressions, and one study stand on a more elevated site that had been heavily fertilized.

The most common forest site type was VT and the least common CT (Fig. 5). The sample plots belonging to the MT type, the most fertile forest site type included in this study, were mainly located in the Juupajoki — Ruovesi area.

Sites with *Vaccinium* type vegetation were divided into two groups on the basis of the thickness of the humus layer. Sites with humus layer thinner than 5 cm were included in VT, and those with a thicker humus layer in 'VT with a thick humus layer'. In spite of the fact that the vegetation did not clearly differ from the *Vaccinium* type, there was reason to believe that the sites with a thick humus layer belong to the *Vaccinium-Myrtillus* type, which is typical above 140—150 meters (a.s.l.) on eluviated, rather fine-textured moraine formations. The *Vaccinium* type in the Cajanderian sense has a thin humus layer and is found on warm, coarse soils (Keltikangas 1959). Determination of the forest site type is based on the ground vegetation of mature stands (Cajander 1926). Soil preparation before regeneration, artificial tree species selection and the young development stage of the tree stand changes the ground vegetation and makes the determination of forest site types difficult in some cases. The dominant tree species of VMT is usually spruce, but after a forest fire it can also be pine or birch (Kalela 1952). In the ground vegetation *Vaccinium myrtillus* and *Hylocomium splendens* are more abundant

Table 4. Mean disease intensity in the different forest site types. X = mean, SD = standard deviation, N = number of sample plots. According to the Kruskal-Wallis test there were no significant differences between groups in either data set.
Taulukko 4. Tuhoaste eri metsätyypeillä. X = keskiarvo, SD = keskihajonta, N = koealojen määrä. Kruskalin-Wallisin testin mukaan ryhmien välillä ei ollut merkittäviä eroja kummassakaan aineistossa.

Disease intensity (%) – *Tuhoaste (%)*		Forest site type — *Metsätyyppi* CT	VT	'VMT'	MT	VT pal.	MT pal.
Ruovesi data — *Ruoveden aineisto*	X	35	35	32	31		
	SD	5	10	11	13		
	N	2	31	16	23		
Multia data — *Multian aineisto*	X	27	39	51	56	51	50
	SD	33	38	37	15	36	31
	N	8	15	29	3	26	10

than on VT, and indicators of paludification such as *Carex globularis* and *Polytrichum commune* are common (Kalela 1952). The reason for the low coverages of *Hylocomium splendens* on all the sample plots may be that the study sites had been burnt over and sown with pine seed after final cutting of the previous tree generation. *Hylocomium* returns very slowly after a forest fire, and is abundant only in spruce-dominated forests (Siren 1955).

There were no statistically significant differences between the disease intensities of different forest site types in either data set (Table 4). The Kruskal-Wallis H value is 4.97 (P = 0.419) for the Multia data and 4.69 (P = 0.196) for the Ruovesi data. When the data from the VT and CT sites were combined into one group and compared with the combined data for the moister forest site types, the difference was statistically significant in the Multia data (Kruskal-Wallis H = 4.33, P = 0.037). The VT and CT sites are probably healthier because their sites are also more elevated (the average site elevation is 11 m for the dry — semi dry and 7 m for the moist forest site types, H = 7.47, P = 0.006).

The diversity of vegetation expressed as species number correlated slightly with disease intensity (Table 5). This could be explained by the improved growing conditions for the ground vegetation on sites with a declining tree stand.

32. Soil

Most of the sample plots were situated on medium coarse sand tills and fine-sand tills (Fig. 6). According to the field test, there was a significant amount of clay only in one stand. Silty tills were found in five stands and on two of the three clear-cut areas. The

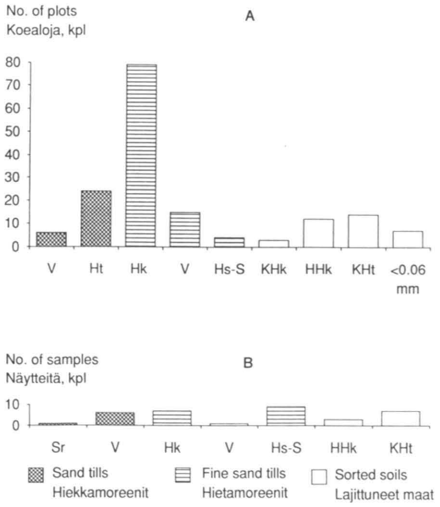


Fig. 6. Soil type distribution of the sample plots (a) and clear-cut areas (b). Abbreviations: Sr = gravelly, V = ordinary, Hk = sandy, Ht = fine sandy, Hs-S = silty and clayey, KHk = coarse sand, HHk = fine sand, KHt = fine fine-sand, < 0.06mm = fine finesand, silt and clay.
Kuva 6. Koealojen sijainti eri maalajeilla ja avohakkuualojen maanäytteiden maalajijakauma. Pylväiden alla olevat lyhenteet: Sr = sorainen, V = varsinainen, Ht = hietainen, Hk = hiekkainen, Hs-S = hiesuinen-savinen, KHk = karkea hiekka, HHk = hieno hiekka, KHt = karkea hieta, <0,06mm = hieno hieta - savi.

proportion of the fine fractions (< 0.06 mm) ranged from 6 to 73 % and was 26.8 % on average (Fig. 7).

The proportion of fine fractions correlated neither with the disease intensity (Table 5), nor with the site elevation (rs = 0.013). In the stand growing on the finest soil the disease intensity decreased with increasing proportion of fine soil fractions. At Multia the proportion of fine fractions increased with the altitude above sea level (r = 0.623, P < 0.001).

The average proportion of fine fractions in the clearcut areas was 23 %, and varied between 2 and 53 %. In one of the three areas the proportion of fine fractions increased towards the bottom of the depression. In all areas the disease intensity increased towards the bottom of the depression (Aalto-Kallonen & Kurkela 1985).

Iron-humus or humus podsols were found on 58 of the sample plots, and the rest (105 plots) were iron podsols. Iron-humus and humus podsols are formed on sites where the watertable is at least temporarily high (Troedsson & Nykvist 1973). The average disease intensity in both data sets is slightly higher on soils affected by groundwater (Table 6). In the Ruovesi data the difference was significant (P = 0.05). However, these sample plots were also located lower down in the depressions (Table 6).

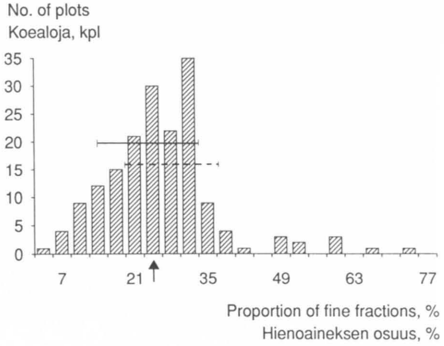


Fig. 7. The percentage of fine fractions (< 0.06 mm) in the mineral soil samples. The following values are presented for comparison: ——— proportion of fine fractions in pine forest soils in Southern Finland (Viro 1947), — — — — average proportion of fine fractions in Finnish tills (Virkkala 1969), ——> the 25 % limit (cf. Lähde 1974).

Kuva 7. Hienoaineksen (raekoko < 0.06 mm) osuus mineraalimaassa tutkituilla aloilla. Kuvaan on merkitty seuraavat vertailuarvot: ——— hienoaineksen osuus eteläsuomalaisten männiköiden maaperässä (Viro 1947), - - - - hienoaineksen keskimääräinen osuus Suomen moreeneissa (Virkkala 1969), ——> hienoainesta 25 % (ks. Lähde 1974).

Table 5. Correlations between environmental characteristics and disease intensity. Key to symbols: r = parametrical correlation coefficient, rs = Spearman rank correlation coefficient, *, **, *** indicate significance of r and rs at the 5 %, 1 % and 0.1 % levels.

*Taulukko 5. Ympäristötekijöiden ja tuhon vakavuuden väliset korrelaatiot. Merkinnät r = parametrinen korrelaatiokerroin, rs = Spearmanin järjestyskorrelaatiokerroin, *, **, *** ilmaisevat r:n ja rs:n merkitsevyyden 5 %, 1 % ja 0,1 % tasoilla.*

		Disease intensity — *Tuhoaste*	
		Multia data *Multian ain.*	Ruovesi data *Ruoveden ain.*
Vegetation — *Kasvipeite*			
Number of plant species — *Kenttäkerroksen kasvilajien lkm*	rs	0.363**	0.002
Number of herb and grass species — *Kenttäkerroksen heinä- ja ruoholajien lkm*	rs	0.384**	0.036
Shannon-Wiever index — *Shannon-Wiever -indeksi*	rs	0.225*	0.030
Coverage of *Sphagnum* spp. — *Rahkasammalten peittävyys*	rs	0.196	0.218
Soil — *Maaperä*			
Thickness of humus layer — *Humuskerroksen paksuus*	r	0.162	—0.113
Thickness of A horizon — *Huuhtoutumiskerroksen paksuus*	r	0.127	0.027
Humus pH — *Humuksen pH*	r	0.369***	0.199
Proportion of fine fractions — *Hienoaineksen osuus*	r	—0.092	—0.089
Topography — *Topografia*			
Site elevation — *Suhteellinen korkeus*	r	—0.557***	—0.666***
Slope gradient — *Rinteen kaltevuus*	rs	0.154	0.414***
Number of sample plots — *Koealojen määrä*		91	72

Table 6. Mean disease intensity and site elevation (height of site above the bottom of the nearest cold air drainage basin) compared between iron podsol soils and temporarily waterlogged iron-humus and humus podsol soils. °, *, ** indicate significant difference between groups at the 10 %, 5 % and 1 % levels.

*Taulukko 6. Keskimääräinen tuho ja kasvupaikan suhteellinen korkeus (korkeus kylmän ilman kerääntymispaikkana toimivan notkon pohjalta) rautapodsoleilla ja pohjavesivaikutteisilla podsoleilla. °, *, ** = ryhmät eroavat merkitsevästi 10 %, 5 % tai 1 % tasolla.*

	Iron p./Iron humus and humus p. *Rautap./Rautahumus- ja humusp.*	
	Multia data *Multian ain.*	Ruovesi data *Ruoveden ain.*
Disease intensity (%) — *Tuhoaste (%)*	44/51	32/38*
Site elevation (m) — *Suhteellinen korkeus (m)*	9/ 6**	12/ 9°
Number of sample plots — *Koealojen määrä*	52/39	53/19

At Multia the average thickness of the A horizon was 10 cm, at Kuru 9 cm and in the Juupajoki-Ruovesi area 6 cm. The thickness of the A horizon did not correlate with disease intensity in any of the areas (Table 5).

The average thickness of the humus layer on unpaludified plots was 6.2 cm at Multia, 3.4 cm at Juupajoki and Ruovesi and 4.3 cm at Kuru. The thickness of the humus layer and total coverage of *Sphagnum* spp., which indicates the degree of paludification, did not correlate with disease intensity (Table 5).

The pH of the humus layer was between 3.5 and 4.8. There was a slight positive correlation between disease intensity and the pH of the humus in the Multia data (Table 5). However, the values were very scattered (Fig. 8), and it is possible that the decline in the tree stand both reduced the production of acid needle and bark litter, and increased the amount of grasses and herbs, thus raising the pH of the humus.

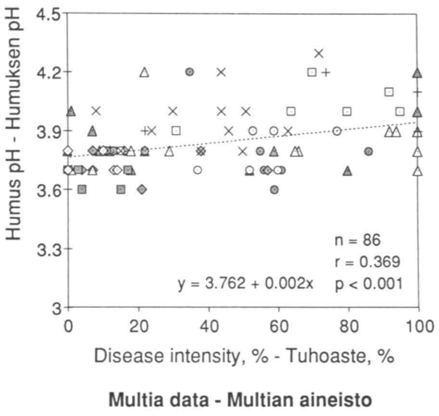


Fig. 8. The relationship between humus pH and damage intensity in the Multia data. The different stands are denoted by different symbols.

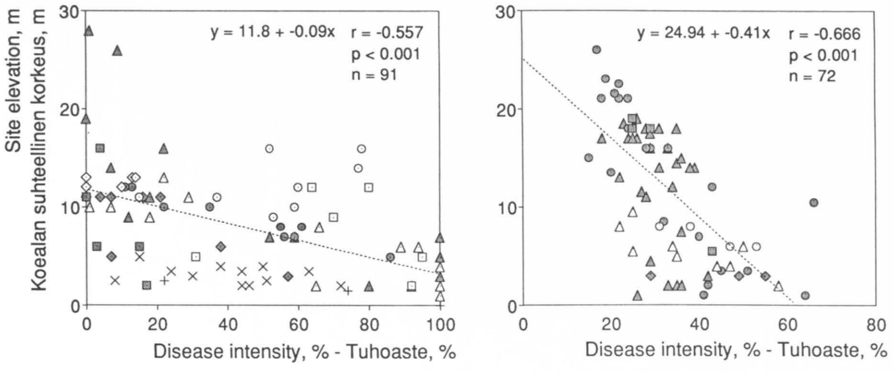
Kuva 8. Humuksen pH:n ja tuhoasteen välinen suhde Multian aineistossa. Eri symbolit viittaavat eri metsiköihin.

33. Topography

The most serious damage in the study area occurred in the depressions and valley bottoms. The disease intensity was significantly negatively correlated with the elevation from the bottom of the cold air basin at both the stand level and the data set level (Fig. 9, Table 5), except for two stands. The regeneration and management of these stands differed from the others. The provenance of the pines could not be traced.

The severely damaged stands detected on the basis of the colour infrared photographs at Multia are presented in Fig. 10. They were mostly located at a height of less than 10 meters above the bottom of the main cold air drainage basin. Stands growing in small depressions in the elevated area between the two valleys were not severely damaged.

Damage leading to the death of the tree top or the whole tree was much less extensive in the Juupajoki-Ruovesi area than at Multia. This appeared in the same manner in the depressions, and if there was a tall spruce stand in the depression the young pines along



A) Multia data - Multian aineisto **B) Ruovesi data - Ruoveden aineisto**

Fig. 9. The relationship between disease intensity and site elevation a) in the Multia , b) in the Ruovesi data. The different stands are denoted by different symbols.

Kuva 9. Tuhon vakavuuden ja kasvupaikan suhteellisen korkeuden välinen korrelaatio a) Multian b) Ruoveden aineistossa. Eri symbolit viittaavat eri metsiköihin.

Table 7. Mean breast height diameter and height of sample trees in different disease intensity classes at Multia. X = mean, SD = standard deviation, N = number of sample plots. Groups combined with a dashed line do not differ significantly according to pairwise t tests.

Taulukko 7. Puiden rinnankorkeusläpimitta ja pituus eri tuholuokissa Multialla. X = keskiarvo, SD = keskihajonta, N = puiden lukumäärä. Katkoviivalla yhdistetyt ryhmät eivät parittaisten t-testien mukaan poikenneet merkitsevästi toisistaan.

		Damage classes — *Tuholuokat*					
		1	2	3	4	5	
Breast height diameter (mm) *Rinnankorkeusläpimitta (mm)*	X	108	109	98	89	71	
	SD	46	41	37	37	33	
	N	421	564	306	179	661	tot. 2 132
Tree height (dm) *Puun pituus (dm)*	X	89	92	85	79	64	
	SD	34	31	28	27	24	
	N	73	99	55	37	65	tot. 329

the stand margin were damaged on the slope. The boundaries of heavy damage followed rather well the contour lines in both areas photographed, and the aspect of the slope appeared to have no effect (Fig. 11).

In the Ruovesi data, the gradient correlated slightly with the disease intensity, the damage increasing with the steepness of the slope (Table 5). If there was a tall, old stand in the narrow depressions in the Juupajoki — Ruovesi area, the young pines on the steepest part of the slope near the stand margin had been affected due to the blockage of downward-moving cold air. The gradient did not correlate with the disease intensity in the Multia data. There were no taller forests below the study areas at Multia.

34. Stand characteristics

The disease intensity did not increase with the density of the tree stand. In the Multia data the diseased trees were thinner on average than the healthy and recovered trees, but they were not significantly shorter (Table 7).

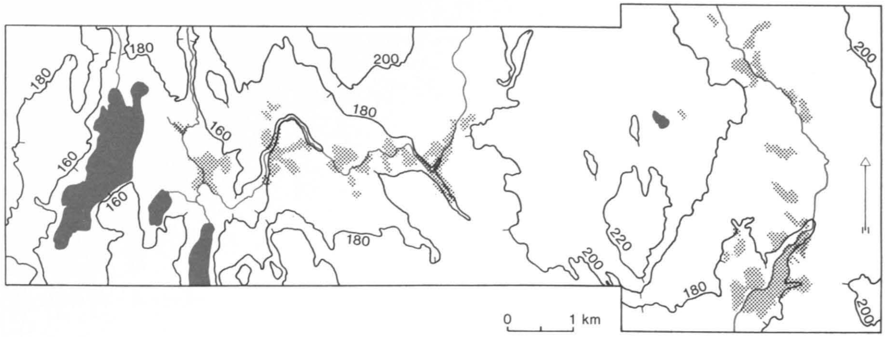


Fig 10. The topographic location of severely damaged stands (shaded areas) not suitable for further growing at Multia. The contour interval is 20 m, the figures indicate altitude above sea level. Lakes and rivers are coloured blue.

Kuva 10. Tuhoutuneet metsiköt Multian ilmakuvausalueella. Korkeuskäyrät 20 m välein, käyrillä olevat luvut ilmaisevat korkeuden meren pinnasta. Järvet ja joet on merkitty sinisellä.

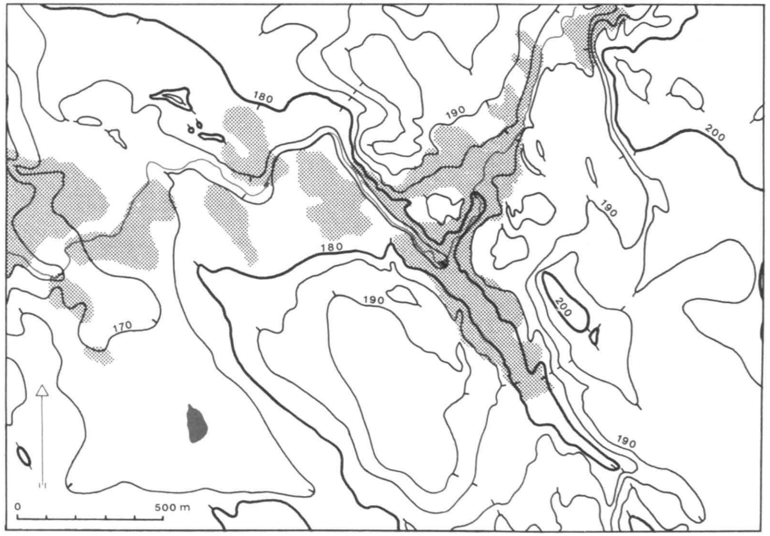


Fig. 11. A detail from Fig. 10 showing the close relationship between topography and severe damage (shaded areas). The contour interval is 5 meters. See Fig. 10 for explanation of symbols.

Kuva 11. Osa kuvasta 10 suuremmassa koossa, jolloin vakavien tuhojen (rasteroidut alueet) ja topografian läheinen yhteys näkyy. Korkeuskäyrien väli on 5 m. Merkinnät kuten kuvassa 10.

35. Comparison of the recovered and severely damaged study plots

The severely damaged study plots lay systematically lower down in the depressions or valleys than the healthy and recovered plots (Table 8). In the Ruovesi data the severely damaged plots were situated on steeper slopes than the healthy and recovered ones. The variation in WARM was similar in both groups.

There was no difference in the average proportion of fine fractions in the mineral soil between the groups (Table 8). In the

Table 8. Comparison of severely damaged and recoverable sample plots. X = mean, MD = median, °, *, **, *** indicate significant difference between the groups at the 10 %, 5 %, 1 % and 0.1 % levels.

*Taulukko 8. Tuhoutuneiden ja toipuneiden koealojen vertailu. X = keskiarvo, MD = mediaani, °, *, **, *** = ryhmien keskiarvot eroavat merkitsevästi 10 %, 5 %, 1 % tai 0,1 % tasolla.*

		Recovered/Damaged — *Toipuneet/Tuhoutuneet*		
		Whole data *Koko aineisto*	Multia data *Multian aineisto*	Ruovesi data *Ruoveden aineisto*
Topography — *Topografia*				
Site elevation (m) *Suhteellinen korkeus (m)*	X	11 / 4***	10/ 5 **	15/ 4***
Slope gradient (1/360°) *Rinteen kaltevuus (1/360°)*	X	3 / 4	3/ 3	3/ 7 **
WARM	MD	2.5 /2.5	2.5/2.5	2.5/2.5
Vegetation — *Kasvipeite*				
Number of plant species *Kenttä- ja pohjakerroksen kasvilajien lkm*	X	8 /10	6/10 ***	10/12
Number of herb and grass species *Kenttäkerroksen heinä- ja ruoholajien lkm*	X	5 / 7 **	3/ 6 ***	6/ 9 *
Shannon-Wiever index *Shannon-Wiever -indeksi*	X	0.57 /0.62	0.49/0.59 *	0.64/0.73
Total coverage of *Sphagnum* spp. (%) *Rahkasammalten peittävyys (%)*	X	0 /0.3***	0/ 2 **	0/ 0
Soil — *Maaperä*				
Thickness of humus layer (cm) *Humuskerroksen paksuus (cm)*	X	4 / 8***	6/10 ***	4/ 3
Thickness of A horizon (cm) *Huuhtoutumiskerroksen paksuus (cm)*	X	8 / 9	9/10	7/ 6
Humus pH *Humuskerroksen pH*	X	3.86 /3.91	3.80/3.89**	3.92/4.00
Proportion of fine fractions (%) *Hienoaineksen osuus (%)*	X	26 /26	25/25	27/28
Median location on the rotated ordination axes *Koealojen sijainti kierretyillä ordinaatio-akseleilla*				
Axis 1 (moisture) *Akseli 1 (kosteus)*	X	2212 /1826**	2137/1659 *	2251/2069
Axis 2 (fertility) *Akseli 2 (viljavuus)*	X	1608 /1920	2132/2071	1529/1330
Tree stand – *Puusto*				
Stand density (trees/ha) *Puuston runkoluku (kpl/ha)*		1832/1582**	1463/1463	2120/1761°
Basal area (m/ha) *Puuston pohjapinta-ala (m/ha)*		16/11***	14/10***	17/12*
Number of sample plots *Koealojen lukumäärä*		108 /55	48/43	60/12

whole data the mean pH of the humus layer was slightly higher and the mean species number of the ground vegetation greater in the severely damaged sample plot group (Table 8). In the Multia data the differences were significant, in the Ruovesi data only the difference in the number of herb and grass species was significant. The more luxuriant vegetation and less acid humus layer on the severely damaged sample plots may be a consequence of the disease in the stand. The average position and scattering of the severely damaged and recovered plots in the ordination diagram was similar on the fertility gradient (Fig. 3, Table 8).

In the Multia data the severely damaged plots were more paludified and the humus layer was thicker (Table 8). These variables correlated slightly with the elevation of the study site (rs = —0.238, P = < 0.05, rs = —0.314, P = < 0.01), and the effect of the microclimate and soil on predisposing the pines could not be separated.

The basal area of the stand was somewhat higher on the recovered plots in both data sets (Table 8). In the Ruovesi data the severely damaged plots had a smaller mean stem number than the recovered plots.

4. Discussion

Heavy *Gremmeniella* infection of pine stands growing in depressions and valley bottoms has been frequently reported (Kohh 1964, Read 1967, Donaubauer 1974, Dorworth 1974, 1978, Aalto-Kallonen & Kurkela 1985). In some investigations pine stands growing on shady and cool, north-facing slopes have been more diseased than those on other aspects (Read 1968, Karlman 1987, Uotila 1988). In Japan no significant difference between aspects was detected (Yokota et al. 1974). Steep middle and upper slopes with good air drainage have been reported to be healthier (Karlman 1987, Yokota et al. 1974).

Slope aspect and gradient did not have a similar relationship with the disease intensity in the area studied. The limits of the severely damaged stands followed the contour lines. This resembles the distribution of frost injuries investigated in Norway: the worst damage was encountered in depressions and on low-lying plateaus, no difference was found between various aspects, and the stand density seemed to have no effect on the disease intensity (Venn 1970).

In Northern Finland a lack of oxygen was reported to account for the poor condition of pine saplings on soils with a fine fraction content of more than 25 per cent (Lähde 1974). About half of the sample plots were situated on finer soils (Fig. 7), but no correlation was found between disease intensity and the percentage of fine fractions. According to Romell (1922), oxygen deficiency is detectable only in water-logged soils and peat soils. Soil waterlogging did not appear to be the principal predisposing factor because severe damage also occurred on bright, rusty coloured iron-podsols that indicated well-aerated soil conditions. The thick humus layer, which was more frequent on severely damaged than on healthy study plots in the Multia data, develops on sites with a cool and humid climate (Aaltonen 1940, Keltikangas 1959).

According to Viro (1947), *Myrtillus* and *Vaccinium* site type soils supporting pine stands in the south of Finland contain from 10 to 34 per cent particles finer than 0.05 mm (calculated from the stone-free fraction of the mineral soil, less than 20 mm). The soils included in the present study were a little finer on average (Fig. 7). The majority of the soil samples in the present material fell between the limits reported by Virkkala (1969) for the average content of fine fractions (below 0,06 mm) in Finnish sand and fine sand tills: 19.6 and 35,8 % dry weight (Fig. 7).

The proportion of fine fractions and site fertility did not increase on moving downwards into the valley bottoms as was the case in Kiikoinen and Hämeenkangas further south (Laiho 1986). The increase in the proportion of fine fractions at higher altitudes encountered at Multia is explained by the supra-aquatic nature of the hilltops. Fine-grained material has not been washed down to valley bottoms by the post-glacial sea like in the sub-aquatic areas. The highest glacial shorelines in the study area lie around 160 meters above present sea level (Sauramo 1940, Aartolahti 1976). All the sample plots at Kuru, most at Multia, and about half of those at Juupajoki and Ruovesi were located at an altitude above 160 meters.

No typical vegetational pattern or forest site type of the severely affected stands could be detected. In both the TWINSPAN classification and the forest site type classification the mean disease intensities were lowest in groups with microclimatically more favourable sites than the other groups. If the data had been larger and had included plots from totally disease-free areas, more pronounced vegetational differences might have been found between the healthy, microclimatically favourable sites and the diseased, cool and humid sites.

Soil fertility exceeding that of soils naturally supporting pine forests has, according to some investigations, contributed to the susceptibility of pines to heavy *Gremmeniella* infection (Kujala 1950, Kowalski & Domanski 1983). Forest types more fertile than natural pine habitats were lacking from the data. The most fertile forest type encountered in the study was the *Myrtillus* type which, although being usually spruce-dominated, can become naturally covered by pine after a forest fire (Cajander 1926). The other frequently spruce-dominated, moist forest type in the study area, the *Vaccinium-Myrtillus* type, appears on poor soils that are well suited to pine (Keltikangas 1959). The semi dry *Vaccinium* and the dry *Calluna* site types are usually pine dominated (Cajander 1926).

According to Nevalainen & Uotila (1984), pines growing on *Myrtillus* type sites seem to be more diseased than those on *Vaccinium* type sites. This means that an increase in soil fertility inside the natural habitat of pine also increases the susceptibility of pine. Similar results were obtained when the growth rate of *Gremmeniella abietina* mycelium was measured in two naturally regenerated pine sapling stands: it was greater in saplings growing on the more fertile site (Kurkela & Norokorpi 1979). In the present study, site fertility seemed to have no effect on the disease intensity. In Central and Northern Sweden young plantations of pine growing on poor soils and at high altitudes have also suffered from severe *Gremmeniella* attacks (Kohh 1964). The most severe damage was similarly located in the depressions and valley bottoms, and was attributed to the 'harsh' microclimate of these sites.

In Central and Western Europe the moist and shady microclimate prevailing in dense pine stands has been shown to promote *Gremmeniella* infection (Read 1968, Gremmen 1972, Donaubauer 1974). On the other hand, Kallio et al. (1985) reported that the number of recoverable trees was greater in dense pine stands. In this work, disease intensity did not increase with stand density. One reason for this could be that the most severely damaged stands have suffered from the disease for a long time, and this may have decreased the stand density already in the early development stages of the stand.

Increment losses caused by the disease are most likely the main cause of the smaller diameter of the severely damaged trees compared to healthy ones (cf. Aalto-Kallonen & Kurkela 1985).

5. Conclusions

The results indicate that the main predisposing factor in the study area is an unfavourable microclimate. At Multia the most serious damage was concentrated on the slightly slanting lower slopes of the two main valleys. The stands in small depressions at higher elevations were not severely damaged. The relief at Ruovesi — Juupajoki study area was lower and ruptured. Severe damage was less extensive, but appeared in the same manner on sites where descending cold air could be blocked. The soil was suitable for pine in depressions, and on slopes and hilltops. No typical vegetational pattern or forest site type of the severely damaged stands could be detected.

Depressions that function as cold air drainage basins should not be regenerated with pine. Instead, *Betula pubescens* Ehrh. could be used, and it would later provide shelter for the frost sensitive but *Gremmeniella* resistant spruce seedlings. Shelterwood felling of a mature stand could also be carried out in order to promote natural regeneration of spruce. The use of a prolonged rotation time should also be considered.

If clear felling of upper slopes is being planned and the low-lying stands are to be retained for further growth, the margin of the remaining stand must be designed to allow the downward flow of air. Otherwise saplings growing near the old forest margin will be subjected to frost pocket conditions.

Topographic maps are helpful in management planning. The *Gremmeniella* infection risk can be high even in a shallow depression if there is no further outlet for cold air and the catchment area is large.

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Total of 71 references

Seloste

Versosurman vaivaamien männiköitten kasvupaikkaominaisuudet Keski-Suomessa. I: Kivennäismaat

Johdanto

Tutkimuksen tavoitteena oli niiden kasvupaikkojen tunnistaminen ja rajaaminen, joilla versosurmariskin takia ei pidä kasvattaa mäntyä. Aikaisemmin on todettu alavilla mailla, notkelmissa ja tiheissä metsiköissä vallitsevan kylmän, varjoisan ja kostean paikallisilmaston altistavan mäntyjä (mm. Read 1967, 1968, Aalto-Kallonen & Kurkela 1985, Uotila 1988). Maaperän hienojakoisuuden, ravinteisuuden ja ajoittaisen hapettomuuden on arveltu pahentavan tuhoa (Kurkela 1984). Tässä työssä tarkastellaan topografian, kasvillisuuden, maaperän laadun ja metsikön tiheyden suhdetta tuhon voimakkuuteen versosurmaan sairastuneissa männiköissä.

Aineisto ja menetelmät

Tutkittuja metsiköitä on yhteensä 16. Ne sijaitsevat Multian, Juupajoen, Kurun ja Ruoveden kunnissa (kuva 1). Tutkittaviksi valittiin 20—40-vuotiaita versosurman vaivaamia männiköitä, siten että tuhoalueiden erilaiset kasvupaikkatyypit tulisivat edustetuiksi. Metsiköt olivat iältään 20—40-vuotiaita, valtapituus vaihteli 5—14 m, runkoluku 300—3700 kpl/ha ja pohjapinta-ala 3—30 m^2/ha. Männyn osuus pohjapinta-alasta oli keskimäärin 94 %. Multialla puuston runkolukuun on laskettu mukaan tuhon jälkeen kaadettujen puiden kannot.

Juupajoen, Kurun ja Ruoveden koealueet oli perustettu Metsäntutkimuslaitoksen aikaisempien versosurmatutkimusten yhteydessä (Alajärvi 1987, Antti Uotila, Helsingin yliopisto, Metsäasema, SF-35500 Korkeakoski, julkaisematon). Niiden puustotunnukset oli mitattu ja versosurmaisuus arvioitu vuosina 1983-86. Multialla metsikköön sijoitettiin 5—10, 1—2 aarin ympyräkoealaa tuhoasteen muutoksen suuntaiselle linjalle. Koealalta mitattiin puusto ja sen versosurmaisuus, tutkittiin maannos kolmesta pisteestä, mitattiin rinteen kaltevuus ja suunta sekä kuvattiin kasvillisuus neljältä neliömetrin suuruiselta ruudulta. Kustakin maannoksen kuvaamispisteestä otettiin näyte humuksen happamuuden ja maaperän raekoostumuksen määritystä varten. Rinteen suunnan ja kaltevuuden avulla määrättiin ekspositiion lämpimyyttä kuvaava tunnus WARM (Kuusipalo 1985). Peruskartalta (1:20 000) katsottiin koealan korkeus meren pinnasta (absoluuttinen korkeus) ja lähimmän kylmän ilman kerääntymispaikkana toimivan notkon pohjalta (suhteellinen korkeus). Koealoja kertyi yhteensä 163. Lisäksi kolmelta Aalto-Kallonen & Kurkelan (1985) tutkimukseen sisältyneeltä versosurman takia paljaaksi hakatulta alueelta tutkittiin maan raekoostumus. Kenttätyöt tehtiin syksyllä -86 ja kesällä -87. Koealojen kasvillisuus kuvattiin heinä- ja elokuussa -87.

Maaperän viljavuuden kuvaajina käytettiin kasvillisuustunnuksia. DECORANA-ordinaatioanalyysin ja TWINSPAN-luokitteluanalyysin (Gauch 1982, Mikkola & Jukola-Sulonen 1984) avulla järjestettyä aineistoa tarkasteltiin kasvilajien tunnettujen kasvupaikkavaatimusten valossa (Kujala 1926a, 1926b, 1926c).

Tuhoalueiden rajaamiseksi ilmakuvattiin Multialla noin 8000 hehtaarin laajuinen metsäalue kesällä 1987. Ruovedellä ja Juupajoella oli kesällä 1985 ja 1986 ilmakuvattu kaksi aluetta, yhteensä 6000 ha (Alajärvi 1987). Kuvat otettiin väri-infrapunafilmille mittakaavassa 1:8000.

Juupajoella, Kurussa ja Ruovedellä versosurmatuhon määrä kunkin puun latvuksessa oli arvioitu prosentteina (Uotila 1985). Multialla männyt luokiteltiin versosurman aiheuttaman latvuksen kuolemisen perusteella viiteen tautiluokkaan.

Tulokset

Tärkein versosurmatuhon vakavuuteen vaikuttava tekijä oli kasvupaikan korkeus kylmän ilman kerääntymispaikkana toimivan notkelman pohjalta (suhteellinen korkeus, taulukko 5). Multialla ilmakuvissa näkyi tuhojen keskittyminen suurien, useiden kymmenien metrien syvyisten notkelmien pohjille ja alaville tasanteille (kuvat 10 ja 11). Muutamien metrien syvyiset notkelmat suhteellisen korkealla eivät olleet pahoja tuhoalueita. Korkeuskuvaltaan pienimuotoisemmalla, Ruoveden-Juupajoen alueella vakavat, latvan ja koko puun kuolemiseen johtaneet tuhot olivat pienialaisia. Nekin esiintyivät alueilla minne yläpuolisilta rinteiltä kirkkaina öinä valuva kylmä ilma kerääntyy. Ruoveden ja Juupajoen koealoihin liittyi pieniä kapeahkoja notkelmia, joissa oli korkea korpikuusikko. Varttuneen kuusikon ja nuoren männikön rajalle rinteen jyrkimpään osaan oli muodostunut vakavan tuhon alue.

Eri viljavuustasoille kuuluvien metsätyyppien välillä ei ollut tilastollisesti merkitsevää eroa versosurmatuhon vakavuudessa (taulukko 4). Pintakasvillisuudesta tehdyn numeerisen analyysin perusteella toipuneiden ja tuhoutuneiden koealojen sijainti viljavuusakselilla oli samanlainen (kuva 3). Koealat kuuluivat mustikka-, puolukka-mustikka-, puolukka- ja kanervatyyppiin (kuva 5).

Suurin osa koealoista sijaitsi keskikarkeilla hiekka-ja hietamoreeneilla (kuva 6). Maaperän hienojakoisuudella ei ollut vaikutusta tuhon vakavuuteen (taulukko 5). Kivennäismaan hienoainessisältö (alle 0,06 mm rakeet) ei kasvanut notkelmien pohjille päin. Savimaita tutkimusalueilla ei ollut.

Seisovan pohjaveden tuholle altistavaa vaikutusta ei voinut erottaa notkelman pienilmaston vaikutuksesta, sillä pohjavesivaikutteiset maannokset sijaitsivat keskimäärin alempana kuin rautapodsolit (taulukko 6). Toisaalta vakavat tuhot eivät rajoittuneet pohjaveden vaivaamille maille vaan niitä oli myös rautapodsoleilla, joiden kirkkaan ruosteenruskean rikastumiskerroksen katsotaan ilmentävän hyvää happitilannetta.

Puuston tiheyden lisääntyessä tuho ei kasvanut. Tähän saattaa olla syynä se, että pahimmilla tuhoalueilla tautia on ollut pitkään ja se on saattanut harventaa puustoa jo sen varhaisessa kehitysvaiheessa.

Johtopäätökset

Kylmän ilman kerääntymispaikkoina toimivien, hallaisten notkelmien uudistamista männylle tulisi välttää. Yläpuolisen alueen päätehakkuun yhteydessä paljaaksi hakattu notkelma kannattaa uudistaa esim. hieskoivulle, jonka alle syntyy myöhemmin kuusikko. Paljaaksi hakkuun sijasta notkelmaan voitaisiin jättää riittävä verhopuusto, jonka alla kuusi voisi uudistua. Kiertoajan pidentämistä voisi myös harkita.

Jos notkelmaan jätetään puusto yläpuolisen alueen hakkuun yhteydessä, täytyy katsoa ettei tulevan taimikon reunaan muodostu kylmän ilman taskua. Jäävä puusto pitäisi rajata ja käsitellä niin että sen latvus jää kokonaisuudessaan taimikon kasvupaikkaa alemmaksi.

Kylmän ilman kerääntymispaikat kannattaa etsiä kartalta, sillä matalaltakin näyttävässä notkelmassa versosurmariski voi olla suuri, jos kylmä ilma ei pääse valumaan pois ja sen kerääntymisalue on laaja.

Appendix. Species abbreviations.
Liite. *Lajinimien lyhenteet.*

ANDR POLI = *Andromeda polifolia*
AULA PALU = *Aulacomnium palustre*
BETU PEN2 = *Betula pendula (shrub)*
BETU PUB2 = *B. pubescens (shrub)*
BETU PUB3 = *B. pubescens (dwarf shrub)*
BRAC SPP. = *Brachythecium spp.*
CALA ARUN = *Calamagrostis arundinacea*
CALA EPIG = *C. epigejos*
CALA PURP = *C. purpurea*
CALL VULG = *Calluna vulgaris*
CARE CANE = *Carex canescens*
CARE GLOB = *C. globularis*
CLAD ARBU = *Cladina arbuscula*
CLAD RANG = *C. rangiferina*
CLAD STEL = *C. stellaris*
CLAD SPP. = *Cladonia spp.*
DESC FLEX = *Deschampsia flexuosa*
DICR MAJU = *Dicranum majus*
DICR POLY = *D. polysetum*
DICR SCOP = *D. scoparium*
DRYO CART = *Dryopteris carthusiana*
EMPE NIGR = *Empetrum nigrum*
EPIL ANGU = *Epilobium angustifolium*
EQUI SYLV = *Equisetum sylvaticum*
ERIO VAGI = *Eriophorum vaginatum*
GYMN DRYO = *Gymnocarpium dryopteris*
HIER MURO = *Hieracium sylvatica*
HYLO SPLE = *Hylocomium splendens*
JUNI COM2 = *Juniperus communis (shrub)*
JUNI COM3 = *J. communis (dwarf shrub)*
LEDU PALU = *Ledum palustre*
LINN BORE = *Linnaea borealis*
LUZU PILO = *Luzula pilosa*
LYCO ANNO = *Lycopodium annotinum*
MAIA BIFO = *Maianthemum bifolium*
MELA PRAT = *Melampyrum pratense*
MELA SYLV = *M. sylvaticum*
MELI NUTA = *Melica nutans*
ORTH SECU = *Orthilia secunda*
OXAL ACET = *Oxalis acetosella*
PICE ABI2 = *Picea abies (shrub)*
PICE ABI3 = *P. abies (dwarf shrub)*
PINU SYL2 = *Pinus sylvestris (shrub)*
PINU SYL3 = *P. sylvestris (dwarf shrub)*
PLEU SCHR = *Pleurozium schreberi*
POHL NUTA = *Pohlia nutans*
POLY COMM = *Polytrichum commune*
POLY JUNI = *P. juniperinum*
POLY STRI = *P. strictum*
POPU TRE2 = *Populus tremula (shrub)*
POTE EREC = *Potentilla erecta*
PTIL CRIS = *Ptilium crista-castrensis*
RUBU CHAM = *Rubus chamaemorus*
RUBU IDAE = *R. idaeus*
RUBU SAXA = *R. saxatilis*
SALI AURI = *Salix aurita*
SALI PHYL = *S. phylicifolia*
SALI SPP. = *S. spp.*
SOLI VIRG = *Solidago virgaurea*
SORB AUC2 = *Sorbus aucuparia (shrub)*
SORB AUC3 = *S. aucuparia (dwarf shrub)*
SPHA ANGU = *Sphagnum angustifolium*
SPHA FUSC = *S. fuscum*
SPHA GIRG = *S. girgensohnii*
SPHA MAGE = *S. magellanicum*
SPHA NEMO = *S. nemoreum*
SPHA RUSS = *S. russowii*
TRIE EURO = *Trientalis europaea*
VACC MICR = *Vaccinium microcarpum*
VACC MYRT = *V. myrtillus*
VACC OXYC = *V. oxycoccos*
VACC ULIG = *V. uliginosum*
VACC VITI = *V. vitis-idaea*

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