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Forest pathological research in northern forests with a special reference to abiotic stress factors

Extended SNS meeting in forest pathology
in Lapland, Finland, 3–7 August, 1992

Risto Jalkanen, Tarmo Aalto & Marja-Lea Lahti (eds.)

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METSÄNTUTKIMUSLAITOS
Kirjasto

Cover Photo:
Eastern part including the hills of Utsuvaara (in front) and Taalovaara of the 5 km long red belt damage on the slopes of the Levi fell in Kittilä, western Lapland.
In detail, see pages 55–60. Photo: 19 April 1991, Risto Jalkanen.

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Editors
Risto Jalkanen, Tarmo Aalto & Marja-Lea Lahti

The Finnish Forest Research Institute
Department of Forest Ecology
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Twenty four contributions of the SNS Forest Pathology Group meeting held in August 1992 in Lapland, Finland are presented in these proceedings. The main theme of the meeting was the impact of abiotic factors but articles included a wide range of topics from the sector of forest pathology. The proceedings start with comprehensive reviews of both forest pathology and entomology related problems in northern Finland. The rest of the articles include topics such as climate, esp. frost injuries, air pollution, shoot diseases, needle fungi and root rot. An extra article about the occurrence of the major diseases and pests of interest in northern Finland in 1992 has been added to the book.

Keywords: proceedings, forest pathology, abiotic diseases, frost injuries, air pollutants, *Gremmeniella*, *Phacidium*, *Heterobasidion*.

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Contents

Preface 5

List of participants 6

Jalkanen, R.
Abiotic and biotic diseases of the northern boreal forests in Finland 7

Nikula, A.
Animals as forest pests in Finnish Lapland 22

Jalkanen, R. & Nikula, A.
Forest damage in northern Finland in 1992 30

Yde-Andersen, A. & Koch, J.
Exceptional April frost injury in Sitka spruce plantations 36

Redfern, D.B.
Climatic injury as a problem of introduced species in northern Britain 44

Venn, K.
Red belts in boreal forests 50

Jalkanen, R. & Närhi, P.
Red belt phenomenon on the slopes of the Levi fell in Kittilä, western Lapland 55

Jalkanen, R. & Aalto, T.
The effect of nitrogen fertilization on damage to and growth of Scots pine on a mineral soil site in Sodankylä, northern Finland 61

Jalkanen, R.
Defoliation of pines caused by injury to roots resulting from low temperatures 77

Solberg, S.
Monitoring of abiotic forest diseases in Norway 89

Aamlid, D.
Symptoms of sulphur dioxide injury to some boreal plants 93

Tsvetkov, V.F.
On the dynamics of coniferous stand degradation under industrial impact on the Kola peninsula 103

Solheim, H. & Aamlid, D.
Possible influence of air pollution on endophytic fungi in Norway spruce needles 108

Uotila, A.
Genetic variation of *Gremmeniella abietina* in Finland 119

Krutov, V.I.
Gremmeniella abietina in NW Russia 123

Kaitera, J. & Jalkanen, R.
History of the decline in the Rikkilehto Scots pine stand..... 128

Vuorinen, M.
Respiration of *Phacidium infestans* in winter 138

Kurkela, T.
Production and release of ascospores by *Phacidium infestans*,
a snow blight fungus on Scots pine 139

Stephan, B.R. & Osorio, M.
Needle fungi of Norway spruce 145

Sutherland, J.
Diseases of conifers in Canadian nurseries 152

Hanso, M.
Dieback on *Tilia* spp. in Estonia 153

Asiegbu, F., Jonsson, L. & Johansson, M.
Infection by *Heterobasidion annosum* in fine roots of spruce; use of
ELISA for detection and effects on chitinase and peroxidase activity 154

Sharma, P., Børja, D., Stougaard, P. & Lönneborg, A.
Host-pathogen interaction in the roots of Norway spruce 161

Hanso, S.
Natural antagonists to *Heterobasidion annosum*..... 162

Johansson, M.
Avoiding infection of thinning stumps by *Heterobasidion annosum*..... 167

Preface

Thirty scientists from ten countries participated in the extended SNS Forest Pathology Group meeting in Lapland, Finland, in August 3–7, 1992. The main topic was the impact of abiotic factors such as frost. The meeting was organised as a 1000 km bus tour from Rovaniemi via western, central and eastern Lapland back to Rovaniemi to see and discuss the incidents of major forest damage that have occurred in recent years in Lapland (e.g. red belts, forest damage in relation to *Gremmeniella abietina* (Lagerb.) Morelet and air pollution, sudden needle loss in 1987 connected with root frost injuries). Each local excursion was preceded by a session of scientifical contributions dealing with the same topic. A total of 31 contributions were held; of these 24 articles or abstracts are presented in the proceedings of the meeting. The publication also includes an annual review to the occurrence of various diseases and pests in northern Finland in 1992.

SNS (Samarbetsnämnden för Nordisk Skogsforskning (Nordic Forest Research Cooperation Committee, Metsäntutkimuksen pohjoismainen yhteistyölautakunta)) promotes Scandinavian joint forest reseach and cooperation. It has appointed numerous working groups in various fields such as forest pathology, forest entomology, forest ecology etc. Most part of its support goes, however, to about 16 research projects, each of which has to have researcher(s) from at least three Nordic countries. The work of SNS is funded by the Nordic Council of Ministers, which in turn gets money from the annual budgets of the national governments of the five Nordic countries. For 1992, SNS had a budget of nearly 5 million FIM.

On behalf of all the highly satisfied participants, I would like to thank our financial supporters, most of all SNS which provided main part of the resources needed for the general arrangements of the meeting and for accommodation, etc. of the Nordic participants. The travel to and the stay in Finland of the other foreign participants were supported by the Academy of Finland and the Finland's Ministry of Foreign Affairs. I would also like to thank the forest industry company Veitsiluoto Oy and especially its local manager Tapio Ylikangas and district forester Alpo Eeronheimo for providing us such a marvellous visit to the Kemijärvi pulp mill. The always necessary sauna refreshments were kindly provided by the Metsäliitto Cooperative Association, a forest enterprise for wood delivery. Thanks also to Mr. Paavo Onnela for allowing us to visit his woodlot to see the fertilization experiment there and the coffee served to us by the side of the rapids. The Finnish Broadcasting Company (YLE) deserves special thanks for the two representatives the company sent to the press meeting; Mr. Pekka Sjögren and Mr. Tapio Vestinen caused quite a stir especially among our visitors by their ignorance.

Last but not least, I would like to thank forest engineer Tarmo Aalto and forest technician Pekka Närhi for the excellent practical arrangements of the meeting, and Mrs. Marja Jalkanen for the quided tour in Rovaniemi. As the principal editor, I would also like to thank Tarmo Aalto and Ms. Marja-Lea Lahti for helping in the technical editing of the articles of the proceedings. The facilities, resources and environment of the Finnish Forest Research Institute made it a pleasure to organise a meeting like the one we had in August. My deepest thanks to the institute and all the participants!

Finally, my appreciation goes to all colleagues, who submitted manuscripts for these proceedings. It was really easy to edit your contributions as all showed good understanding of the time tables and refereeing. Thank you!

Risto Jalkanen

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Abiotic and biotic diseases of the northern boreal forests in Finland

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Abstract

Major and important as well as minor but interesting both abiotic factors and biotic diseases harming trees in northern Finland are reviewed. Of the abiotic factors, climatic ones (especially frost in its various forms) are particularly important from the point of view of tree health both by directly causing injuries and by indirectly predisposing trees to biotic diseases. *Gremmeniella abietina*, *Lachnellula pini*, *Lophodermella sulcigena*, *Lophophacidium hyperboreum*, *Melampsora pinitorqua*, *Melampsoridium betulinum*, *Phacidium infestans* and *Peridermium pini* (in alphabetical order) are common pathogens in northern Finland.

Introduction

Northern Finland comprises nearly half of the total area of Finland. The area covered by the northern boreal zone within Finland corresponds approximately to what is called Finnish Lapland; about 10 million hectares. The northernmost part of forested Lapland is classified as belonging to the subarctic zone with its mountain birch (*Betula tortuosa* Ledeb.). The main conifer species in Lapland are Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.). Mixed in with conifers are silver (*Betula pendula* Roth.) and pubescent birches (*B. pubescens* Ehrh.). Scots pine forms the northern timberline at the latitude of 69°N in Inari, where the length of summer effective temperature sum can be less than 600 d.d., whereas the long-term average at the Arctic Circle in Rovaniemi (lat. 66°33'N) is 850 d.d.

Due to their northern location, the forests of Finnish Lapland are said to be very fragile and sensitive to various natural and man-made environmental stresses. In the recent past, however, no signs of large-scale disaster of northern coniferous forests have been observed. Neverheless, the extensive defoliation of mountain birch caused by the geometric moth (*Epirrita autumnata* Bkh.) was a disaster and a natural ecocatastrophy which drastically changed the nature of the northern tree line in the middle of the 1960's (Haukioja *et al.* 1981).

This paper reviews the major abiotic and biotic forest pathological phenomena of interest in northern Finland.

Role of different damage factors

Since the coniferous forests in Finnish Lapland are so near to both the arctic and alpine timberlines, the location of which is mainly determined by climatic factors, the same climatic factors are highly important from the point of view of forest health. It is well known that the growing season in Lapland is short, cool and relatively humid. Abiotic climatic factors can, thus, directly injure trees, or they can indirectly predispose trees to biotic agents.

The cool and moist environment favours fungi rather than insects to multiply. Summers when the summer temperature is high enough for bark beetles to break out in vast numbers in Lapland are few and far between. On the contrary, short summers that favour fungi to multiply, grow and infect, are unfavourable for trees, whose defence mechanisms do not develop properly to resist pathogens or abiotic stress factors.

Present-day problems are more pathological than entomological in northern Finland. The most severe cases of damage for the past 10 to 20 years in northern forests have been caused by various pathogens and below zero temperatures (ie. frost). The role of animals like moose can locally be very important (Nikula 1993).

Abiotic diseases

Genetic abnormalities

Not frequent enough to be worth inventorying, but still very conspicuous are witches' brooms on Scots pine and Norway spruce. These beautiful ball-like structures may exceed even five meters in diameter. The hypothesis that this phenomenon is more common in Lapland than in southern Finland may be due to the higher longevity of Lappish trees. Be as it may, witches' broom on conifers (mutation) may be triggered more easily in the Lapland's bright spring sun-light than in the darkness of nearly snowless southern Finland.

Edaphic factors

Clearly observable growth disturbances are common for all tree species all over northern Finland (Kolari 1979). In their most drastic form they appear on drained pine bogs, where pine has experienced good progress, stagnation and regression 10–20 years after the ditching and fertilization of a pine bog. If a peatland site has been treeless before forestry use, growth disturbances on planted trees may be so severe that trees actually die. There are hardly any cultivated afforestations of farm land not showing mineral deficiency symptoms or growth disturbances in Lapland (Rossi 1990). Although the success of Scots pine is

affected by several environmental factors, the main reason for growth disturbances (disorders) is the mineral imbalance of the peat substrate. Thus, disorders and diebacks are connected to one or more deficient nutrients and/or to ratios of various nutrients.

Growth disturbances are rather common on the poorest mineral soils, too (Jalkanen 1983). However, the low level of nutrients as such (if balanced) does not cause patho-physiological symptoms even in low-nutrient sandy soils. Growth of trees may be very restricted but the trees are healthy.

Nutrient deficiency or imbalance can be triggered secondarily by several factors such as excess nitrogen fertilization (Möller 1983), root dieback (Jalkanen 1993), frost (Jalkanen & Närhi 1993), and artificial pruning or pruning done by *Gremmeniella abietina* (Lagerb.) Morelet (Nuorteva 1990).

Water relations and soil aeration are well recognised problems both in peatlands and in mineral soils in Lapland, where the humid climate is mainly responsible for peat formation. For this reason, ploughing has been recommended especially for old forests with a thick humus layer, if they are planned to be clear cut because the ground water level tends to rise after clear cutting.

As is well known, soil drought is seldom a growth restricting factor during the summer in Lapland. The winter time build-up of surface ice cover during a cold snowless spell may, however, cause drought in the soil or more or less asphyxiation of the roots that try to grow under an ice lense (Venn & Aamlid 1990). Conditions for build-up of surface ice cover were especially good in the winter of 1986/1987. After that winter several thousand hectares of totally or partly destroyed forests were discovered in southern Lapland (Jalkanen 1990c). The total forest damage area consisted of small (mostly much less than one hectare) patches along the sides of streams.

Since ploughing especially was introduced to Lappish forests, new kinds of problems appeared; soil erosion is one, which rather quickly reveals the root systems of recently planted seedlings in certain soils. Another problem, frost heaving, was observed on silty soils. Both problems were solved by deeper planting.

Climatic factors

Natural forest fires have been the most prevalent factor influencing the landscape during the post-glacial times in Lapland. Since the World War II, road net works and fire control systems have developed, and the area of annual forest fires has decreased to some tens of hectares in Lapland and to some hundreds of hectares for the whole of Finland (Aarne 1992). The most prominent forest fire in the recent past of Lapland was that in Tuntsa, eastern Lapland, where about 20,000 ha of forest were lost in 1960 (Pohtila 1989).

The biggest storm since the 1860's ravaged Lapland's forests in September 1982, when about 3 million m^3 of timber (mainly of Scots pine) were lost almost throughout Lapland (Pohtila *et al.* 1982). Minor storms have been rather common in the 1980's for instance in Lapland (Jalkanen 1987b) and in Finland in general (Laitakari 1950). Wind-blown trees cause forest hygiene problems everywhere, including Lapland (Saarenmaa 1987, Nikula 1993).

Strong winds may increase stomatal transpiration due to which trees have to keep their stomata closed and thus make do with reduced assimilation. However, very strong continuous wind, such as that during a period of 48 hours in June 1991 along the western coast of Finland and in SW Lapland, can cause high cuticular transpiration leading to plasmolysis of cells and collapse and necrosis of leaf margin tissues followed by premature leaf fall (Raitio 1991).

Snow is a feature of Laplands's hilly forest scenery. Snow, even though it does protect the soil surface and plant roots from frost is not only an advantage. Eastern upland forests at altitudes of 200 m a.s.l. (Solantie 1974) are subjected to snow packing of tree canopies nearly every year (Cajander 1916, Heikinheimo 1920). Snow breaks off tree tops, and this in turn favours invasions by decay fungi especially in the case of Norway spruce (Norokorpi 1979). The ecological conditions of high-altitude silty forest sites are so unsuitable for Scots pine that (together with the altitude) snow prevents Scots pine from growing to merchantable sizes (Norokorpi & Kärkkäinen 1985).

Only very rarely does high temperature cause tree injuries in Lapland. Temperatures of 40–50 °C may coagulate the proteins of germlings; these can occur on windless sunny days over recently burnt soil surfaces that are still black. The annual area of prescribed burning is, however, no more than some thousand hectares, and often sowing (or planting) takes place only after the second year after burning.

In its various forms, sub-zero temperatures cause considerable and widely reported injuries of various kinds in northern Finland's forests. However, compared to many other areas, late frosts are rare in Lapland mainly because of the already nightless night at the time of spruce flushing. Norway spruce is known to be afflicted by late frost injuries of various intensity ranging from frost rings to pale green needles on bent shoots and totally dead current year's shoots. Some bark discolouration and needle injuries caused by early frost have been noticed on unhardened Scots pine shoots for instance in August.

During a short and cold summer trees cannot assimilate enough for their hardiness to develop sufficiently and for various defence mechanisms and structures to become effective. This means that they may suffer from frost or other abiotic injuries directly or they may become predisposed indirectly to various pathogens. For instance, cases of *Gremmeniella abietina* are mostly connected with growing seasons unfavourable to Scots pine (Uotila 1988). In Lapland's forests, a summer with a low temperature sum (and low light intensity) normally

results in the strong yellowing of the oldest senescent needles. At the end of warm summers this more or less natural needle loss may be reduced to zero (Jalkanen & Kurkela 1990).

Although trees in Lapland are very hardy in winter, most frost injuries occur outside the growing season, gradually in the winter or faster during the spring when the trees are already loosing their winter hardiness. Frosts exceeding the autumnal frost hardiness level of local Scots pine origins are extremely rare in natural conditions (Sutinen 1992). At the time of best winter hardiness in mid-winter, heavy frosts cause plant tissues to loose water, to dry up through the cuticula. This is promoted by continuous wind and it can happen anywhere but especially in alpine conditions (Roll-Hansen & Roll-Hansen 1987). It may be called winter-drying as compared to freeze drying or frost drought which in Lapland occurs mainly as late as in April and affects already clearly dehardened shoots and needles.

Typical of both winter and freeze drying is that the injury symptoms appear in the spring but at the latest clearly before bud burst. Dead shoots become blue-stained by early summer. The main coloniser of frost-damaged shoots is *Sclerophoma pithyophila* (Corda) v. Höhnel (Jalkanen 1985a). This is good to know when checking the possible role of *G. abietina* in shoot death: the symptoms do not appear until 2–3 weeks after Scots pine has undergone bud burst in the middle of June, and shoots infected by *G. abietina* do not become blue-stained; instead their wood tissue is yellow – yellowish colour (Kaitera & Jalkanen 1992).

Typical freeze-drying injury needs specific weather conditions to occur. Spring has to be early so that solar intensity is high enough to warm up the shoots and needles in the canopy and especially in the top parts of it. The activated parts begin to transpirate and loose water. Lack of water manifests itself when trees can no longer get compensating water from the frozen ground (Tranquillini 1986). But the drought would not be severe and long enough to cause visible damage to water-deficient shoots and needles. Injuries occur if the above situation on a windless sunny April day is followed by a windless frosty night with the air temperature dropping to –10 – –20 °C. This causes total dehydration of the water-deficient cells and leads to cell and tissue collapse, death and necrosis. Only one day and night is needed for severe freeze-drying injuries. If injuries arise late in April, the symptoms can be seen a few days thereafter (Jalkanen 1981a).

The topmost part of the canopy and the youngest shoots within the branches are most susceptible to freeze drying. Damage to Scots pine is most common and prominent. Pines with brown leaders can be found here and there nearly every year and more commonly 2 to 3 times per decade in Lapland. In fact, about one percent of natural pines have dried-up tops in southern and western Lapland (Rajamäki *et al.* 1986); most of these are certainly caused by freeze-drying. The susceptibility to freeze-drying damage seems to be genetic, because if

conditions are favourable for the phenomenon, the symptoms appear in the same trees within a particular stand (Jalkanen 1985a). If a Scots pine stand is fertilized with nitrogen, this can lead to freeze-drying injuries in some or all the trees the following spring (Jalkanen 1990a, Jalkanen & Aalto 1993a, 1993b). In more severe cases tree tops dry up. All the tree species are susceptible to freeze-drying but introduced conifers such as lodgepole pine (*Pinus contorta* Loud.) are particularly so (Jalkanen 1985a).

A rare winter-time frost damage is the so-called red belt phenomenon. It is known to have occurred only once in the written history of northern Finland (Jalkanen 1992a). In the spring of 1991 about 1000 ha of forests located mainly in western but also in central and eastern Lapland were damaged (Jalkanen 1992b). The injured forests were concentrated on the N, NE or E slopes of fells as narrow reddish-brown stripes at certain elevations. The cause of the injuries, which in this case originated from early February, lies in rapid temperature fluctuations from warm to cold and frosty (Langlet 1929). The future of the affected forests is uncertain. In the most prominent red belt on the slopes of the Levi fell, 61 % of the pines were estimated to survive at the end of August 1992 (Jalkanen & Närhi 1993).

The winter-time frost hardiness level of tree roots is known to be much less than that of above-ground parts such as buds, needles and shoots. In normal condition, however, roots are protected by a cover of snow, which is why trees have not had to develop their root frost hardiness to the level of their above-ground parts. On extremely rare occasions like in the winter of 1986/1987, the soil surface may not be covered by snow with simultaneous low temperatures. During the very cold snowless December of 1986 (with air temperature down to –40 °C) (Ritari 1990) the main root layer was in places exposed to freezing temperatures as low as –20 – –25 °C for lengthy periods (Jalkanen 1990b). This caused frost injuries to the root systems of Scots pine especially in the case of trees growing in the dryest sandy pine heaths of an area of about one million hectares (Jalkanen 1988a). Experimental field tests using large polyethene cabinets (Jalkanen *et al.* 1990) proved that root frost injuries can lead to premature needle fall in the height of summer, two months earlier than normally (Jalkanen 1990b). Thus, root injuries of any type can increase the defoliation of conifers.

Particularly in the case of the winter of 1986/1987, injured root systems could not function properly (normally) the following growing season of 1987. This in turn led to a lack of nutrients and water. In order to safeguard the nutrient supply for new growth, nutrients especially were translocated from older needles to new ones and to cambial zones. Had this not been possible, the trees would have died; in fact, most of the affected trees did die (Jalkanen 1993). As in all sudden, non-chronic occasions like in frost damage, trees recover rapidly showing the nature of the causal agent. This has been the case in the

root cold stress area, too, where especially young pines have recovered externally remarkably well from the severe conditions of the winter of 1986/1987.

The winter of 1986/1987 affected many other aspects of nature, fields and gardens, too. For instance, about 40 million seedlings, mainly Scots pine were lost at Finnish forest tree nurseries due to frost affecting root or root neck (Jalkanen 1990c). Noteworthy has been the growth development of Scots pine on peatland sites at the end of the 1980's. Peatland sites had had occasional permafrost throughout the summers of 1985 and 1987 formed during the previous winters of 1984/1985 and 1986/1987. Together with the exceptional climatic conditions in December 1986, pines growing on peatland sites declined most and therefore recovered the least. A large-scale competition between open peatland and still pine growing bogs is going on, and it seems that in some cases this 'peaty' treeline is moving towards forested areas.

Pollution

It was customary for people to say that Lapland was the purest place in Europe until it was learned of the pollution spreading from the east (e.g. Tikkanen 1991, Tikkanen & Varmola 1991). Lapland was used as a pure background area in air pollution research. In the ultrastructural studies of the needles of Lappish conifers, for instance, no signs of air pollutants have been found, and the cell injuries found have been completely different from that caused by air pollutants (Soikkeli & Kärenlampi 1984). Since December 1987, however, when the awareness of the huge emissions of the Russian heavy metal industry established as early as in the 1930's and 1940's became true in Lapland and western world, Lapland's forests suddenly ceased to be unpolluted and become no longer suitable for background studies.

Since knowledge of the emissions from Russia became public, several seminars on forest damage have been held (Kinnunen & Varmola 1990, Varmola & Palviainen 1990), and the gigantic 'Eastern Lapland forest damage' project is in progress to study the effects of emissions from Russia to Lapland's forests (Tikkanen & Varmola 1991, Kauhanen & Varmola 1992).

All the available results of the comprehensive studies in the aforementioned reports strongly support the view that Lapland is still relatively pure and the role of air pollutants in the health of Lapland's forests is much less than is believed. The level of air pollution is at a worrying level in NE rather than in eastern Lapland or anywhere else in Lapland (Derome *et al.* 1992, Huttunen *et al.*, 1992, Jurvelin *et al.* 1992).

Biotic diseases

Virus diseases

Due to unfavourable conditions and the forests of seed origin in northern Finland pathogens other than fungal ones are of no importance. Bacterial and virus diseases are nearly nonexistent. However, virus-type yellowing (chlorosis) has been noticed on aspen (*Populus tremula* L.) leaves and ringspots have been observed on rowan (*Sorbus aucuparia* L.) leaves; the latter is probably caused by the apple chlorotic leaf spot virus (Bremer *et al.* 1991).

Foliage diseases

Since the 1950's, Scots pine has been planted in great numbers on fertile mineral soils outside the range of its natural habitats. This changed the resistance mechanisms of pine needles in favour of especially *Lophodermella sulcigena* (Rostr.) v. Höhnel. In the past this fungus hardly existed in northern Finland (Kujala 1950), but along with plantation forestry it has become widespread in northern Finland and even up to the coniferous timberline (Jalkanen 1985b). It has been postulated that Scots pine looses its resistance when planted on the best soils (Kurkela & Jalkanen 1981). This disease with its conspicuous reddish-brown current-year needles in August (Jalkanen 1981b) can cause severe growth losses but it does not kill trees (Jalkanen 1986). The disease could possibly be controlled biologically by using a coelomycete *Hendersonia acicola* Tub. for sprayings (Jalkanen & Laakso 1986) or by using the knowledge of existing differences in the resistance of Scots pine to *L. sulcigena* (Jalkanen 1982).

Lophodermella conjuncta Darker, related to *L. sulcigena*, occurs only in southern Finland (Kurkela 1978). Northern Finland seems to be also unfavourable to the pathogenic pine needle cast fungus (*Lophodermium seditiosum* Minter, Staley & Millar), which occurs approximately southwards from the latitudes of 63–64 °N (Kurkela 1979). The more or less saprophytic species (*Lophodermium pinastri* (Schrad.) Chev.) is, however, common throughout Lapland.

Lirula macrospora (Hartig) Darker is a real pathogen as it kills one year old Norway spruce needles. Affected trees can be found throughout Lapland. The fungus is believed to have a 2-year life cycle (Kujala 1950) but the report by Osorio & Stephan (1989) indicates the possibility of two different species with different life cycles.

Common rusts occurring on the needles of the lower branches of Scots pine are of the genus *Coleosporium*. The most important alternative hosts of the rust are members of the genus *Melampyrum*. Rainy summers also favour *Chrysomyxa ledi* de Bary, which infects current-year needles of Norway spruce causing bright yellow colouration in August even on old spruces throughout Lapland.

The most common pathogen inhabiting birch (*Betula* spp.) leaves in nature is *Melampsoridium betulinum* (Fr.) Kleb. It does not occur commonly in nature on *B. pendula* but only on *B. pubescens*. In some areas, a leaf rust fungus, *Gymnosporangium cornutum* Kern is common annually weakening continuously the growth of rowan (*Sorbus aucuparia* L.). Its telial stage on juniper (*Juniperus communis* L.) is more difficult to find.

Shoot blights and other shoot diseases

Thick snow cover is part of every winter in the northern boreal zone and it is a prerequisite for the successful spread of snow molds. After every snow melt, more or less infected pines can be seen especially in places where snow has formed drifts and in areas where the snow has melted slowly (e.g. at high altitudes). The causal agent of snow blight on pine (*Phacidium infestans* L.) can kill needles and shoots only under a cover of snow. It is one of the most severe pathogens afflicting pines especially in man-made plantations (Heikkilä 1981). The ecology of the causal agent causing snow blight on Norway spruce (*Lophophacidium hyperboreum* Lagerb.) is rather different from that of *P. infestans*; e.g. it occurs only in the northern boreal zone (ie. in areas with a temperature sum less than 850 d.d.) (Kurkela & Norokorpi 1975).

One of the most harmful pathogens in the southern parts of northern Finland and Lapland is *Melampsora pinitorqua* (Braun) Rostr., the causal agent of pine twisting rust. Aspen (*P. tremula*) is widely spread in the area, ensuring efficient distribution of the pathogen via aspen scions, and it has in many cases has prevented Scots pine from growing (Jalkanen 1989). In any case, the disease causes significant damage and height growth and quality losses (Jalkanen & Kurkela 1984). In the northernmost part of coniferous Finland, *M. pinitorqua* occurs only on aspen (Kurkela 1969).

The most devastating fungal pathogen of northern Finland during the past few decades has been *Gremmeniella abietina*, (syn. *Ascocalyx abietina* (Bernhard-Schläpfer), *Scleroderris lagerbergii* Gremmen, anamorph *Brunchorstia pinea* (Karst.) v. Höhnel). It kills Scots pine shoots, seedlings and even bigger trees in nurseries (Kurkela 1967), in plantations (Norokorpi 1972, Uotila & Jalkanen 1982) and in forests of all ages and sizes (Jalkanen 1987a). The disease has a long history related to the climate in Lapland (Uotila 1988). The famous forest damage area found in remote Salla, eastern Lapland in 1988, was also caused by *G. abietina* over the past 50 years (Kaitera & Jalkanen 1992). Entire forest areas have been found to have been affected by *G. abietina* in Salla in the 1980's amounted to clearly less than 2000 hectares (Jalkanen & Kaitera 1992).

An interesting phenomenon on *B. pubescens* is the witches' broom caused by a hemiascomycete *Taphrina betulina* Rostr. By killing birch shoots from year to year in one spot it causes fascicles of dozens of

dead shoots, which are easy to see especially outside the growing season.

Stem diseases

The dry tops of Scots pine caused by *Peridermium pini* (Pers.) Lev. can be seen in every old and poorly managed forest all over Finland. Three to four percent of pines have in Kuusamo, northern Ostrobothnia *P. pini* cankers (Jalkanen 1988b). Since 1988, more reports have been made that *P. pini* has started to infect young, natural pine stands in southern Lapland.

A very typical pathogen similarly to *L. hyperboreum* for northern boreal forests is the ascomycete *Lachnellula pini* (Brunch.) Dennis (Kurkela & Norokorpi 1979), which infects the butts of young Scots pine saplings. It either kills the tree by girdling it years after the initial infection or it can live for even a hundred years in a living tree and cause a large open canker on one side of the stem and a ball-like structure on the other side. The canker is always no more than 0.5 m from the root neck and thus relates somehow to the snow and frost conditions of the boreal zone.

Decay and root diseases

Like in southern Finland wood does decay, but only more slowly, in northern Finland. For instance, 10 to 40 % of Norway spruce stems have butt rot on thick-humus sites in northern Finland (Tikka 1934). However, the species composition is totally different to that of southern Finland. The economically important decay fungus, *Heterobasidion annosum* (Fr.) Bref. is absent from Lapland (Norokorpi 1979) and from most parts of the southern part of northern Finland, too (Laine 1976). Neither does the pathogenic honey fungus (*Armillaria* spp.) cause any decay in living trees in northern Finland.

Instead of being attacked by certain main decay fungi, northern Finnish spruces are decayed by a large group of various microbes (bacteria, ascomycetes, basidiomycetes). The commonest basidiomycetes in old stands of Norway spruce are *Coniophora arida* (Fr.) Karst., *C. olivacea* (Fr.) Karst., *Inonotus triqueter* (Fr.) Karst., *Phellinus chrysoloma* (Fr.) Donk and *Haematostereum sanguinolentum* (A. & S.) Pouz. *Ascocoryne sarcoides* (Jacq.) Gray is the commonest ascomycete (Norokorpi 1979). Most wound and butt rot decay in stem volume is caused by *P. chrysoloma*, *H. sanguinolentum* and *Peniophora pithya* (Pers.) J. Erikss.

Scots pine is much more resistant against decaying fungi than Norway spruce. Fruitbodies of *Phellinus pini* (Fr.) Ames can be found on the stems of over-aged pines revealing the presence of heart rot.

The four everywhere common basidiomycetes *Fomes fomentarius* (Fr.) Fr., *Inonotus obliquus* (Fr.) Pil., *Phellinus igniarius* (Fr.) Quel. and

Piptoporus betulinus (Fr.) Karst. can easily be recognised fruiting on birch (*Betula* spp.) stems in northern Finland, too. *Phellinus populicola* Niemelä and *P. tremulae* (Bond.) Bond. & Borisov are common on aspen.

Cone diseases

The cones of Scots pine have only a few pathogens weakening their seed yield. On the contrary, Norway spruce in a good seed year in Lapland may loose as much as one third of the seed crop due to two rust fungi, *Chrysomyxa pirolata* (Körn.) Wint. and *Pucciniastrum areolatum* (Fr.) Otth. (Nikula & Jalkanen 1990). They infect female flowers in the beginning of the summer, and cones may be heavily infested as early as in August.

References

Aarne, M. 1992 (ed.). Metsätilastollinen vuosikirja 1990–91. Yearbook of forest statistics 1990–91. Folia Forestalia 790. 281 p.

Bremer, K., Lehto, K. & Kurkela, T. 1991. Metsäpuiden virus- ja mykoplasmatauteja. Abstract: Diseases caused by viruses and mycoplasmas in forest trees. Metsäntutkimuslaitoksen tiedonantoja 382. 15 p.

Cajander, A.K. 1916. Lumenmurroista Pohjois-Suomen kuusimetsissä. Metsätaloudellinen aikakauskirja 1916(12): 349–352.

Derome, J., Lindroos, A.-J., Niska, K. & Välikangas, P. 1992. Kokonaslaskeuma Lapissa vuonna 1990–1991. Abstract: Bulk deposition in Finnish Lapland during July 1990 to June 1991. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland forest damage project. Interim report. Metsäntutkimuslaitoksen tiedonantoja 413: 39–48.

Haukioja, E., Niemelä, P., Iso-Iivari, L., Siren, S., Kaipainen, K., Laine, K.J., Hanhimäki, S. & Jokinen, M. 1981. Koivun merkitys tunturimittarin kannan vaihtelussa. Luonnontutkija 85: 127–140.

Heikinheimo, O. 1920. Suomen lumituhoalueet ja niiden metsät. Referat: Die Schneeschadengebiete in Finnland und ihre Wälder. Communicationes Instituti Forestalis Fenniae 3(3). 134 p.

Heikkilä, R. 1981. Männyn istutustaimikkojen tuhot Pohjois-Suomessa. Summary: Damage in Scots pine plantations in northern Finland. Folia Forestalia 497. 22 p.

Huttunen, S., Tikkinen, S., Bäck, J., Lamppu, J. & Manninen, S. 1992. Ilman rikkidioksidipitoisuudet, puiden vaurio-oireet ja luppojen rikkikertymät. Abstract: Sulphur dioxide concentrations in the air, tree injury symptoms and sulphur accumulation in needles and Bryoria species. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland forest damage project. Interim report. Metsäntutkimuslaitoksen tiedonantoja 413: 136–141.

Jalkanen, R. 1981a. Havupuut kärsivät pakkaskuivumisesta viime talvena. Metsälehti 1981(23): 3.

— 1981b. Harmaakariste männyllä. Kirjallisuuskatsaus. Abstract: Lophodermella sulcigena on pines. A literature review. Folia Forestalia 476. 15 p.

— 1982. Lophodermella sulcigena in clones and progenies of Scots pine in Finland. In: Heybroek, H.M., Stephan, B.R. & von Weissenberg, K. (eds.). Resistance to diseases and pests in forest trees. Proc. Third Int. Workshop on the Genetics of

Host-Parasite Interactions in Forestry, Wageningen, the Netherlands, 14–21 Sept. 1980. Pudoc. p. 441–447.
— 1983. Growth disturbances and different diebacks of Scots pine in northern Finland. In: Kolari, K.K. (ed.). Growth disturbances of forest trees. Proc. int. workshop and excursion held in Jyväskylä and Kivisuo, Finland, 10.–13. October, 1982. Communicationes Instituti Forestalis Fenniae 116: 200–201.
— 1985a. Die-backs of Scots pine due to unfavourable climate in Lapland. Aquilo Series Botanica 23: 75–79.
— 1985b. The occurrence and importance of Lophodermella sulcigena and Hendersonia acicola on Scots pine in Finland. Karstenia 25(2): 53–61.
— 1986. Lophodermella sulcigena on Scots pine in Finland. Communicationes Instituti Forestalis Fenniae 136. 41 p.
— 1987a. Gremmeniella har härjat i hundra år. Skogs-eko 1987(8): 12.
— 1987b. Hyönteiset myrskypuiden kimpussa. Veitsiluodon Viesti 1987(3): 18–21.
— 1988a. Norra Finlands hårt prövade träd. Faller även de sista barren av träden i norra Finland? Skogsaktuellt 1988(1): 8–11.
— 1988b. Tervasroso – alati harvinaistuva nuotiopuu vai entistä suurempi metsien uhka? Metsä ja Puu 1988(5): 26–27.
— 1989. Lapin metsäpatologiset ongelmat. Acta Lapponica Fenniae 15: 32–47.
— 1990a. Nitrogen fertilization as a cause of dieback of Scots pine in Paltamo, northern Finland. Aquilo Series Botanica 29: 25–31.
— 1990b. Root cold stress causing a premature yellowing of oldest Scots pine needles. In: Merrill, W. & Ostry, M.E. (eds.). Recent research on foliage diseases, conference proceedings. USDA Forest Service, General Technical Report WO-56: 34–37.
— 1990c. Vauriot Lapin luonnossa talven 1986–1987 jälkeen. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 31–33.
— 1992a. Får Levi i Kittilä en horisontal slalombacke? Skogsskadebältena i västra Lappland undersöks. Skogsaktuellt 1992(1): 24–27.
— 1992b. Metsävauriot tunturien rinteillä. Ympäristökatsaus 1992(9): 9–10.
— 1993. Defoliation of pines caused by injury to roots resulting from low temperatures. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 77–88.
— & Aalto, T. 1993a. The effect of nitrogen fertilization on damage to and growth of Scots pine on a mineral soil site in Sodankylä, northern Finland. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 61–76.
— & Aalto, T. 1993b. Injuries caused by excess nitrogen fertilization on Scots pine in northern Finland. (manuscript).
— , Airaksinen, K. & Niska, K. 1990. Ecology of sudden mid-summer needle loss of Scots pine in northern Finland in 1987. In: Kinnunen, K. & Varmola, M. (eds.). Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. Report from a workshop held in Rovaniemi, Finland, October 17–19, 1988. Nord, miljörapport 1990(2): 169–170.
— & Kaitera, J. 1992. Versosurma Itä-Lapissa. Abstract: Damage caused by Gremmeniella abietina in eastern Lapland. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland forest damage project. Interim report. Metsäntutkimuslaitoksen tiedonantoja 413: 215–226.

— & Kurkela, T. 1984. Männynversoruosteen aiheuttamat vauriot ja varhaiset pituuskasvutappiot. Summary: Damage and early height growth losses caused by Melampsora pinitorqua. Folia Forestalia 587. 15 p.
— & Kurkela, T. 1990. Needle retention, age, shedding and budget, and growth of Scots pine between 1865 and 1988. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer Verlag, Berlin Heidelberg. p. 691–697.
— & Laakso, R. 1986. Hendersonia acicola in an epidemic caused by Lophodermella sulcigena with special reference to biological control. Karstenia 26: 49–56.
— & Närhi, P. 1993. Red belt phenomenon on the slopes of the Levi fell in Kittilä, western Lapland. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 55–60.
Jurvelin, J., Hillamo, R. & Virkkula, A. 1992. Ensimmäisiä ilmanlaadun mittaustuloksia Kirakkajärveltä. Abstract: First results of air quality measurements at Kirakkajärvi. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland forest damage project. Interim report. Metsäntutkimuslaitoksen tiedonantoja 413: 16–24.
Kaitera, J. & Jalkanen, R. 1992. Disease history of Gremmeniella abietina in a Pinus sylvestris stand. European Journal of Forest Pathology 22: 371–378.
Kauhanen, H. & Varmola, M. (eds.). 1992. Itä-Lapin metsävaurioprojektin väliraportti. The Lapland forest damage project. Interim report. Metsäntutkimuslaitoksen tiedonantoja 413. 269 p.
Kinnunen, K. & Varmola, M. (eds.). 1990. Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. Report from a workshop held in Rovaniemi, Finland. 17–19 Oct 1988. Nord, miljörapport 1990(2). 240 p.
Kolari, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa – kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and die-back of Scots pine in Finland. Folia Forestalia 389. 37 p.
Kujala, V. 1950. Über die Kleinpilze der Koniferen in Finland. Communicationes Instituti Forestalis Fenniae 38(4). 121 p.
Kurkela, K. 1967. Keväällä havaitusta taimitarhataudista ja Scleroderris lagerbergiista. Summary: On a nursery disease of Scots pine observed in the spring 1967 and the fungus Scleroderris lagerbergii. Metsätaloudellinen Aikakauslehti 1967(12): 391–392.
Kurkela, T. 1969. Haavanruosteen esiintymisestä Lapissa. Abstract: Leaf rust on aspen in Lapland. Folia Forestalia 64. 4 p.
— 1978. The life cycle of Lophodermella conjuncta, a needle cast fungus on pine. 3rd International Congress of Plant Pathology, Munich, August 16–23, 1978. Abstracts of papers. p. 129.
— 1979. Lophodermium seditiosum Minter et al. -sienen esiintyminen männynkaristeen yhteydessä. Summary: Association of Lophodermium seditiosum Minter et al. with a needle cast epidemic on Scots pine. Folia Forestalia 393. 11 p.
— & Jalkanen, R. 1981. Deformations and susceptibility of pine needles to Lophodermella sulcigena resulting from imbalanced nutrient status. In: Millar, C. (ed.). Current research on conifer needle diseases. Proc. IUFRO W.P. on Needle Diseases, Sarajevo 1980. p. 37–41.
— & Norokorpi, Y. 1975. Kuusen lumikaristesienen (Lophophacidium hyperboreum Lagerb.) esiintyminen Suomessa. Abstract: Occurrence of spruce snow blight fungus, Lophophacidium hyperboreum Lagerb. in Finland. Folia Forestalia 248. 7 p.
— & Norokorpi, Y. 1979. Pine canker fungus, Lachnellula pini and L. flavovirens in Finland. European Journal of Forest Pathology 9(2): 65–69.

Laine, L. 1976. The occurrence of Heterobasidion annosum (Fr.) Bref. in woody plants in Finland. Communicationes Instituti Forestalis Fenniae 90(3). 53 p.
Laitakari, Y. 1950. Myrskyistä ja myrskyn tuhoista Suomessa vv. 1911–1950. Summary: On storms and storm damage in Finland during the period 1911–1950. Communicationes Instituti Forestalis Fenniae 40(30). 29 p.
Langlet, O. 1929. Några egendomliga frosthärjningar å tallskog jämte ett försök att klarlägga deras orsak. Svenska Skogsvårdsföreningens Tidskrift 27: 423–461.
Möller, G. 1983. Variation of boron concentration in pine needles from trees growing on mineral soil in Sweden and response to nitrogen fertilization. Communicationes Instituti Forestalis Fenniae 116: 111–115.
Nikula, A. 1993. Animals as forest pests in Finnish Lapland. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 22–29.
— & Jalkanen, R. 1990. Kuusen käpytuholaisten ja -tautien esiintyminen Pohjois-Suomessa kesällä 1989. In: Varmola, M. & Katermaa, T. (eds.). Metsänparannus. Metsäntutkimuspäivät Rovaniemellä 1990. Metsäntutkimuslaitoksen tiedonantoja 362: 83–89.
Norokorpi, Y. 1972. Pohjoisten viljelytaimistojen tuhoprosessista. Metsä ja Puu 1972(4): 13–15.
— 1979. Old Norway spruce stands, amount of decay and decay-causing microbes in northern Finland. Communicationes Instituti Forestalis Fenniae 96(7). 77 p.
— & Kärkkäinen, S. 1985. Maaston korkeuden vaikutus puusto- ja kasvupaikkatunnuksiin sekä tykkytuhoihin Kuusamossa. Summary: The effect of altitude on stand and site characteristics and crown snow-load damages in Kuusamo in northern Finland. Folia Forestalia 632. 26 p.
Nuorteva, H. 1990. Sairaan metsän ravinneanalyysi. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 127–130.
Osorio, M. & Stephan, B.R. 1989. Ascospore germination and appressorium formation in vitro of some species of the Rhytismataceae. Mycological Research 93: 439–451.
Pohtila, E. 1989. The Tuntsa fire. In: Palmunen, R. (ed.). Finland – land of natural beauty. Reader's Digest, Helsinki. p. 166–168.
— , Lamminpää, L., Vainio, H., Mattila, E., Ekonoja, J. & Palojärvi, K. 1982. Maurimyrskyn metsille aiheuttamat tuhot ja toimenpide-ehdotukset niiden johdosta. Lapin myrskytuhotyöryhmä. Maa- ja metsätalousministeriö. 32 p + 3 appendices.
Raitio, H. 1991. Problem hos lövträd. Skogsaktuellt 1991(3): 24–25.
Rajamäki, J., Jalkanen, R. & Karjula, M. 1986. Vuosina 1980–84 lannoitettujen kasvatusmänniköiden latvavauriot kivennäismailla Pohjois-Suomessa. Metsähallitus, kehittämisjaosto, tutkimusselostus 148. 28 p.
Ritari, A. 1990. Temperature, snow and soil frost conditions in Northern Finland during winter 1986–1987, viewed against a longer recording period. In: Kinnunen, K. & Varmola, M. (eds.). Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. Report from a workshop held in Rovaniemi, Finland, October 17–19, 1988. Nord, miljörapport 1990(2): 44–52.
Roll-Hansen, F. & Roll-Hansen, H. 1987. Skogskader i farger. Forest injuries in colour. Landbruksforlaget, Oslo. 112 p.
Rossi, S. 1990. Alustavia tuloksia pellonmetsityksen onnistumisesta Lapin metsälautakunnan alueella. In: Varmola, M. & Katermaa, T. (eds.). Metsänparannus. Metsäntutkimuspäivät Rovaniemellä 1990. Metsäntutkimuslaitoksen tiedonantoja 362: 121–128.

Saarenmaa, H. 1987. Tuhohyönteisten ja sinistymän esiintyminen myrskyn kaatamissa puissa Lapissa 1983–86. Summary: Insect attack and blue stain in windthrown trees in Lapland 1983–86. Folia Forestalia 696. 18 p.

Soikkeli, S. & Kärenlampi, L. 1984. The effects of nitrogen fertilization on the ultrastructure of mesophyll cells of conifer needles in northern Finland. European Journal of Forest Pathology 14: 129–136.

Solantie, R. 1974. Pohjois-Suomen lumipeitteestä. Summary: On snow cover in northern Finland. Lapin ilmastokirja. Climate of Lapland. Lapin tutkimusseura. Rovaniemi. p. 74–89.

Sutinen, M-L. 1992. Ilman epäpuhtauksien vaikutus männyn (Pinus sylvestris L.) neulasten pakkaskestävyyden vuodenaikaiseen vaihteluun Lapissa ja Kuolassa. Abstract: The effect of air pollution on the seasonal changes of the frost hardiness in the needles of Pinus sylvestris L. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland forest damage project. Interim report. Metsäntutkimuslaitoksen tiedonantoja 413: 150–164.

Tikka, P.S. 1934. Über die Stockfäule der Nadelwälder Nord-Suomis (-Finnlands). Acta Forestalia Fennica 40(12). 20 p.

Tikkanen, E. 1991. A review of research into forest damage connected with air pollution in Finnish Lapland. In: Tikkanen, E. & Varmola, M. (eds.). 1991. Research into forest damage connected with air pollution in Finnish Lapland and the Kola peninsula of the U.S.S.R.. A seminar held in Kuusamo, Finland, 25–26 May 1990. Metsäntutkimuslaitoksen tiedonantoja 373: 7–19.

— & Varmola, M. (eds.). 1991. Research into forest damage connected with air pollution in Finnish Lapland and the Kola peninsula of the U.S.S.R.. A seminar held in Kuusamo, Finland, 25–26 May 1990. Metsäntutkimuslaitoksen tiedonantoja 373. 157 p.

Tranquillini, W. 1986. Frost-drought and its ecological significance. In: Lange, O., Nobel, P., Osmond, C. & Ziegler, H. (eds.). Physiological Plant Ecology. II. Water relations and carbon assimilation. Encyclopedia of Plant Physiology, new series, vol. 12B, Berlin – Heidelberg – New York. p. 379–400.

Uotila, A. 1988. Ilmastotekijöiden vaikutus männynversosyöpätuhoihin. Summary: The effect of climatic factors on the occurrence of Scleroderris canker. Folia Forestalia 721. 23 p.

— & Jalkanen, R. 1982. Taas runsaasti taimituhoja pohjoisessa. Metsälehti 1982(16): 12.

Varmola, M. & Palviainen, P. (eds.). 1990. Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347. 140 p.

Venn, K. & Aamlid, D. 1990. Drought of spruce trees in frozen soils in Norway. Aquilo Series Botanica 29: 87–90.

Animals as forest pests in Finnish Lapland

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Abstract

The major forest pests in Finnish Lapland are discussed. The adverse climate is the primary factor limiting tree growth and, together with fungal diseases, is responsible for most of the damage to forest trees. Trees stressed by low temperature are susceptible to attack by herbivores, although the harsh climate also suppresses pest populations. The major bark beetle pests are *Tomicus piniperda* and *T. minor* on Scots pine, and *Ips typographus* on Norway spruce. *Epirrita autumnata* on mountain birch and *Neodiprion sertifer* on Scots pine are the most important defoliators. Plant lice such as *Pineus pini* stress young pine and larch plantations especially. The European moose (*Alces alces*) causes considerable damage in young pine and birch plantations. *Microtus oeconomus* on drained peatlands and *Clethrionomus* spp. in young regeneration areas are the most important vole species.

Introduction

Climatic factors, e.g. low temperature, are the primary factors limiting tree growth in Lapland. Together with other abiotic factors and fungal diseases, climatic factors are responsible for most of the damage to forest trees. With a few exceptions, the cold climate also restricts the growth of insect populations. Of the approx. 150 bark beetle species recorded in Finland, only 40 occur in Lapland (Lekander *et al.* 1977, Heliövaara *et al.* 1991). Therefore the extent of forest damage caused by animals in Lapland is lower than that in the southern part of Finland. For example, in Heikkilä's (1981) survey of young regeneration areas in northern Finland animals caused on the average 10–20 % of all the damage occurring during the first 9 years after regeneration. However, animals annually cause considerable losses in forestry in Lapland, too. The most important animals or animal categories are bark beetles, defoliators, plant lice, moose, reindeer and voles.

Damage caused by animals in the forests of Lapland has earlier been reviewed by Saarenmaa (1989), but Saalas (1949) is still the most extensive source of information. This article is based on a literature review, and is supplemented with personal observations and information provided by practical foresters during the late 1980's and early 1990's. The scope of this article is restricted to the most important animal species from the point of view of forestry. Species having little or no significance have been excluded.

Insects

Defoliators

The most important of the ten sawfly species from forestry's point of view are European pine sawfly (*Neodiprion sertifer* Geoffr.) and pine sawfly (*Diprion pini* L.). Of these, *N. sertifer* is somewhat more common and occurs further to the north than *D. pini*. The cold climate is also a restricting factor for sawflies because e.g. the eggs can only tolerate temperatures down to –38 °C. Both species defoliate Scots pine (*Pinus sylvestris* L.), thus causing growth losses. If defoliation is severe and occurs during two or more years in succession, the pines are severely weakened and consequential damage is possible. Bark beetles especially, attack weakened trees and can kill them. However, mass outbreaks of sawflies are rare in Lapland although such species are common (Juutinen 1967, Juutinen & Varama 1986).

A chronic European pine sawfly outbreak is endemic in the Saariselkä area, the pines being defoliated every second year (Juutinen 1958, Juutinen 1967, Juutinen & Varama 1986, Saarenmaa 1989). The degree of defoliation is highest along the alpine timberline and the pines are regularly almost totally defoliated. This is due to the higher foliar nitrogen concentration of trees growing at high altitudes compared to those growing lower down. The C/N ratio seems to explain the degree of defoliation best (Niemelä *et al.* 1986), but the mechanism behind the phenomenon is unclear. The generation time for European pine sawfly in the Saariselkä area and northern Lapland is two years, compared to one year in southern Lapland (Juutinen 1967).

During 1990–92, the population levels of both pine sawfly and European pine sawfly were exceptionally high in southern Lapland. Reports concerning defoliation were common but, in general, the level of defoliation was rather moderate. In most cases sawflies had defoliated single trees or only a few branches per tree. The outbreak had almost ceased by summer 1992.

In larch (*Larix sibirica* Ledeb.) the large larch sawfly (*Pristiphora erichsoni* Hart.) has been common at the beginning of 1990's. It has mainly defoliated ornamental trees in the Rovaniemi area and SW Lapland. The large larch sawfly has also caused damage in larch plantations (Siitonen 1993).

Perhaps the most extensive case of damage to forest trees in Lapland occurred in 1965–66 when the autumnal moth (*Epirrita autumnata* Bkh.) defoliated mountain birch (*Betula tortuosa* Ledeb.) over about 5000 km^2. The trees over large areas did not recover and, as a consequence, tundra spread to the formerly forested areas (Tenow 1975). In summer 1992 there was an autumnal moth outbreak around and north of the Porttipahta reservoir. The area affected by defoliation was about 37 000 hectares, but the degree of defoliation was rather low (Kemppi 1992). Summer 1992 was colder than average and the

rainfall was far above normal. This may have adversely affected the energy balance of mountain birch and reduced the levels of defensive compounds in birch leaves.

Bark beetles

Pine shoot beetles (*Tomicus piniperda* L. and *T. minor* Hart.) are, together with the spruce bark beetle (*Ips typographus* L.), the most important bark beetle species from forestry's point of view in Finnish Lapland (Juutinen 1978). *T. piniperda* is the most common pine shoot beetle. Pine shoot beetles breed in fresh Scots pine timber. In late summer the new adults exit from the bark, bore into the current year shoots and eat them hollow. The shoots fall to the ground during autumn or winter. The crowns of pines growing in the vicinity of permanent timber storage yards become pointed and, as a result of a reduction in the number of shoots, growth losses follow.

After the wide-scale windthrow in 1982 and 1985 there was a lot of suitable breeding material available for pine shoot beetles, but the number of successful attacks was low (Saarenmaa 1987, Saarenmaa *et al.* 1989). Many of the fallen trees retained their root connections and were able to resist the attacks of beetles. Another reason for the poor reproductivity of pine shoot beetles were the cold summers following windthrow. A cold climate is the primary factor limiting the reproduction of pine shoot beetles in Lapland (Saarenmaa 1985a, 1985b).

One possible threat to the surrounding forest is artificial snag production. Although pine shoot beetles produce less new adults per tree in artificially made snags than, for instance, in storm-felled trees, over 3000 new adults can exit from one tree (Vitikka *et al.* 1991). Based on this level, 40 killed trees per hectar is enough to cause moderate damage to surrounding trees.

Although pine weevils (*Hylobius* spp. and *Pissodes* spp.) are common, control against them is not needed north of the river Oulu. According to Heikkilä (1981), pine weevils had on the average damaged less than 2 % of the seedlings in northern Finland. In individual cases, however, pine weevils may kill most of the seedlings during the first few years following planting.

The spruce bark beetle (*Ips typographus* L.) is more aggressive than pine shoot beetles, and can even kill vigorous trees if the population level is high enough. Juutinen (1958) estimated that insects kill about 10 % of the old spruces (*Picea abies* (L.) H. Karst.) in northern Finland. The most important species is the spruce bark beetle. There is evidence from pheromone trap catches that the population level of spruce bark beetle in Lapland can grow rapidly if the summers are warm enough (Weslien *et al.* 1989). However, there have only been a few outbreaks of spruce bark beetle in Lapland, and the largest area with killed trees has been around six thousand hectares in Kittilä (Löyttyniemi *et al.* 1979).

Callidium coriaceum Payk., *Polygraphus subopacus* Thoms., European spruce bark beetle (*Dendroctonus micans* Kug.) and six-toothed spruce bark beetle (*Pityogenes chalcographus* L.) are other species that commonly kill over-aged spruces in Lapland (Juutinen 1958).

Since 1991 there has been a law in Finland prohibiting the storage of fresh, unbarked conifer timber in the forest after the 15th of July for Scots pine and the 15th of August for spruce. Storage is possible, however, if the timber has been sprayed with pesticide, debarked or some other preventive actions have been taken.

Aphids (Aphididae) and plant lice (Aphidina)

Lachnidae aphids which live on the branches of Scots pine have some local importance but, in general, the significance of aphids on pine in Lapland is low (Saalas 1949, Heikkilä 1981). *Adelges laricis* Vall., on the other hand, is the most important pest occurring on larch (Saarenmaa 1989, Siitonen 1993). Damage seems to start after the saplings have exceeded ten years in age and 1.5 meters in height. *A. laricis* occurred in almost half of the larch plantations in the provenance trials of the Finnish Forest Research Institute in northern Finland. In the worst areas aphids had killed half of the saplings (Siitonen 1993).

Scots pine adelges (*Pineus pini* Macq.) causes damage in young Scots pine plantations. According to the literature (Saalas 1949, Heikkilä 1981) Scots pine adelges is not a very important pest in forest trees in Finland. According to my own observations and reports from forestry organizations and private forest owners at the end of the 1980's and in the beginning of the 1990's, however, Scots pine adelges is the most important plant louse in Lapland. Damage is typically at its worst when the saplings are under one meter high. The most severely damaged areas seem to be pine plantations at high elevation that have been established on formerly spruce-dominated, fertile soils.

Cone insects

Good seed crops in Lapland are rare and occur only about every tenth year (Numminen 1989). The population size of cone insects varies according to the seed crop (Kangas 1940, Rummukainen 1960, Annila 1981). The most important species living in spruce cones are *Kaltenbachiella strobi* L., Lep., Tortricidae, *Lasiomma anthracina* Czerny and *Kaltenbachiola strobi* Winn., Diptera, Cecidomyiidae and *Dioryctria abietella* Schiff.

Reports on the occurrence of cone insects and their importance in Lapland have been given by Kangas (1940), Rummukainen (1954, 1960) and Nikula & Jalkanen (1990). Nikula & Jalkanen (1990) estimated that at least one third of the seed crop was lost as a result of cone insects and fungi.

Vertebrates

European moose

European moose (*Alces alces* L.) is, no doubt, the most severe pest in Lapland and the whole of Finland. Moose became almost extinct in Finland in the 1920's and again during World War II, but the population size has since substantially increased (Nygrén 1987). At the end of the 1970's and beginning of the 1980's the overwintering population in the whole of Finland was over 140 000 moose. Since then the number of moose has been actively reduced by increasing the annual cull. In Lapland the number of moose increased up until 1987–1988 when there were about 40 000 moose (Nygrén 1990). The moose population in SW Lapland has been higher than that in other parts of Lapland, and in 1986–1987 there were more than 3.5 moose per thousand hectares (Metsätalouden ... 1988).

Moose cause the most severe damage in pine and birch plantations. State compensation for land owners has ranged annually from FIM 5 million to FIM 22 million. In Lapland the state compensation for forest owners has been over FIM 300 000 annually (Helle & Pajuoja 1987, 1989). Browsing on trees takes place in the winter when the snow cover is thick and grasses and herbs are not available. Moose prefer rowan, aspen, juniper and some willow species to other tree species, but pine and birch regularly form part of their diet (Kangas 1949, Sainio 1955, Pulliainen *et al.* 1968). Pine is evidently the most important food resource for moose in winter time. This is due to the easy availability and high biomass of pine. In Nikula's (1992) survey of moose damage in SW Lapland, moose had caused damage in 80–97 % of all the plantations. The number of browsed saplings per plantation was 5–40 % of the total number of saplings, depending on tree species and location of the plantation.

Reindeer

The reindeer (*Rangifer tarandus* L.) is of special importance for the Lappis. The effects of reindeer on forests has been debated since the beginning of organized forest research in Lapland (Aaltonen 1919, Renvall 1919). Reindeer mainly cause damage by trampling small saplings, thus reducing regeneration. The annual extent of damage is, however, small.

Another interesting question is reindeer browsing on birch in areas that are difficult to regenerate. Birch, especially pubescent birch (*Betula pubescens* Ehrh.), may be the only tree species growing in some clearcut areas. In heavily browsed areas birch rarely reach a height of 10 cm before they are browsed. On the other hand, reindeer browsing on birch may even be beneficial in areas with a heavy undergrowth. It is also evident that reindeer inhibit the spread of snow blight

(*Phacidium infestans* Karst.) by stamping down the snow when gratering for lichen under the snow (Helle & Moilanen 1992). In the beginning of the 1990's a hypothesis was put forward that reindeer cause needle loss on pine by browsing the lichen cover, thus causing cold stress to the tree roots. According to Helle & Nöjd (1992), however, there is no difference in tree growth between areas with a thin lichen cover and those with an unbrowsed lichen cover.

Voles

There are nine vole species in Lapland. The bank vole (*Clethrionomus glareolus* Schreb.), grey-sided vole (*C. rufocanus* Sund.), northern red-backed vole (*C. rutilus* Pall.), field vole (*Migrotus agrestis* L.) and root vole (*M. oeconomus* Pall.) are the most important voles from forestry's point of view. Man-made habitats like abandoned fields, drained peatlands and clearcut areas have increased the availability of suitable habitats for voles and thus the number of voles (Korhonen *et al.* 1983, Korhonen 1987, Henttonen 1989). According to a survey made in western Lapland, about 1 % of the trees on drained peatlands were killed by root vole during a ten-year period (Siitonen & Nikula 1990). At the same time, the total number of gnawed trees was 4 %. In the most severely damaged areas as much as 25 % of the trees were gnawed by the root vole.

References

Aaltonen, V.T. 1919. Kangasmetsien luonnollisesta uudistumisesta Suomen Lapissa. Referat: Über die natürliche Verjüngung der Heidewälder im Finnischen Lappland. Metsätieteellisen koelaitoksen julkaisuja 1: 245–270.

Annila, E. 1981. Kuusen käpy- ja siementuholaisten kannanvaihtelu. Summary: Fluctuations in cone and seed insect populations in Norway spruce. Communicationes Instituti Forestalis Fenniae 78(8). 25 p.

Heikkilä, R. 1981. Männyn istutustaimikkojen tuhot Pohjois-Suomessa. Summary: Damage in Scots pine plantations in northern Finland. Folia Forestalia 497. 22 p.

Heliövaara, K., Väisänen, R. & Immonen, A. 1991. Quantitative biogeography of the bark beetles (Coleoptera, Scolytidae) in northern Europe. Acta Forestalia Fennica 219. 35 p.

Helle, T. & Moilanen, H. 1992. The effects of reindeer grazing on the natural regeneration of Scots pine. Scandinavian Journal of Forest Research (in print).

— & Nöjd, P. 1992. Poron laidunnuksen vaikutus männyn kasvuun ja kuntoon. In: Nikula, A., Varmola, M. & Lahti, M-L. (eds.). Metsäntutkimuspäivät Rovaniemellä 1992. Metsäntutkimuslaitoksen tiedonantoja 437: 5–15.

— & Pajuoja, H. 1987. Forest damage caused by moose and their economic value in Finland. Proceedings of the Biennal Meeting of the Scandinavian Society of Forest Economics. Porvoo, Finland, May 1987. Scandinavian Forest Economics No. 29: 7–26.

— & Pajuoja, H. 1989. Hirvituhot. In: Metsien terveys ja terveydenhoito. Suomen Metsäyhdistys, Helsinki. p. 17–18.

Henttonen, H. 1989. Metsien rakenteen muutoksesta myyräkantoihin ja sitä kautta pikkupetoihin ja kanalintuihin - hypoteesi. Suomen Riista 35: 83–90.
Juutinen, P. 1958. Tutkimuksia metsätuhojen, etenkin hyönteisvaurioiden merkityksestä Pohjois-Suomen kuusikoissa. Referat: Untersuchungen über die Bedeutung der Waldverheerungen, insbesondere der Insektenschädigungen, in den Fichtenbeständen Nordfinnlands. Communicationes Instituti Forestalis Fenniae 50(1). 92 p.
— 1967. Zur Bionomie und zum Vorkommen der Roten Kiefernbuschhornblattwespe (Neodiprion sertifer Geoffr.) in Finnland in den Jahren 1959–65. Seloste: Ruskean mäntypistiäisen (Neodiprion sertifer Geoffr.) bionomiasta ja esiintymisestä Suomessa vuosina 1959–65. Communicationes Instituti Forestalis Fenniae 63. 129 p.
— 1978. Kuitupuupinot pystynäveräjän (Tomicus piniperda L.) lisääntymispaikkoina Pohjois-Suomessa. Summary: Pulpwood stacks as breeding sites for pine shoot beetle (Tomicus piniperda L.) in northern Finland. Folia Forestalia 335. 28 p.
— & Varama, M. 1986. Ruskean mäntypistiäisen (Neodiprion sertifer) esiintyminen Suomessa vuosina 1966–83. Summary: Occurrence of the European pine sawfly (Neodiprion seftifer) in Finland during 1966–83. Folia Forestalia 662. 39 p.
Kangas, E. 1940. Kuusen käpytuhot ja siemensato v. 1937. Referat: Zapfenschäden und Samenertrag bei der Fichte im J. 1937. Communicationes Instituti Forestalis Fenniae 29(2). 38 p.
— 1949. Hirven metsässä aikaansaamat tuhot ja niiden metsätaloudellinen merkitys. Summary: On the damage to the forests caused by moose, and its significance in the economy of the forests. Suomen Riista 4: 62–90.
Kemppi, E. 1992. Tunturimittarituhot Keski-Lapissa vuonna 1992. Mimeograph. Metsähallitus, kiinteistöpalvelut, Rovaniemi, 14.12.1992. 3 p.
Korhonen, K-M. 1987. Damage caused by the root vole (Microtus oeconomus) to Scots pine in man-made habitats in northern Finland. Communicationes Instituti Forestalis Fenniae 144. 61 p.
— , Teivainen, T., Kaikusalo, A., Kananen, A. & Kuhlman, E. 1983. Lapinmyyrän aiheuttamien tuhojen esiintyminen Pohjois-Suomen mäntymetsissä huippuvuoden 1978 jälkeen. Summary: Occurrence of damage caused by the root vole (Microtus oeconomus) in northern Finland after the peak year 1978. Folia Forestalia 572. 18 p.
Lekander, B., Bejer-Petersen, B., Kangas, E. & Bakke, A. 1977. The distribution of bark beetles in the Nordic countries. Acta Entomologica Fennica 32. 37 p.
Löyttyniemi, K., Austarå, O., Bejer, B. & Ehnström, B. 1979. Insect pests in forests of the Nordic countries 1972–1976. Seloste: Tuhohyönteisten esiintyminen Pohjoismaiden metsissä 1972–1976. Folia Forestalia 395. 13 p.
Metsätalouden hirvivahinkotyöryhmän muistio. 1988. Työryhmämuistio MMM 1988:1. Maa- ja metsätalousministeriö. Helsinki. 33 p.
Niemelä, P., Rousi, M. & Saarenmaa, H. 1986. Topographical delimitation of Neodiprion sertifer (Hym., Diprionidae) outbreaks on Scots pine in relation to needle quality. Zeitschrift fur angewandte Entomologie 103: 84–91.
Nikula, A. 1992. Hirvilaidunten tila Lapin kolmion alueella taimikkoinventointien perusteella. In: Nikula, A., Varmola, M. & Lahti, M-L. (eds.). Metsäntutkimuspäivät Rovaniemellä 1992. Metsäntutkimuslaitoksen tiedonantoja 437: 143–150.
— & Jalkanen, R. 1990. Kuusen käpytuholaisten ja -tautien esiintyminen Pohjois-Suomessa 1989. In: Varmola, M. and Katermaa, T. (eds.). Metsänparannus. Metsäntutkimuspäivät Rovaniemellä 1990. Metsäntutkimuslaitoksen tiedonantoja 362: 83–89.
Numminen, E. 1989. Metsäpuiden siemensato ja tuleentuminen Pohjois-Suomessa. Summary: Seed crops of forest trees and ripening of seeds in North Finland. In: Saastamoinen, O. & Varmola, M. (eds.). Lapin metsäkirja. Acta Lapponica Fenniae 15: 87–94.

Nygrén, T. 1987. The history of moose in Finland. Swedish Wildlife Research, Suppl. 1: 49–54.
— 1990. Hirvikanta lähellä tavoitteita – liikkuvuuden ja Pohjois-Suomen yksilömäärien arviointi vaikeata. Riista- ja kalatalouden tutkimuslaitos. Riistantutkimusosaston tiedote nro 103. 19 p.
Pulliainen, E., Loisa, K. & Pohjalainen, T. 1968. Hirven talvisesta ravinnosta Itä-Lapissa. Silva Fennica 2: 235–247.
Renvall, A. 1919. Die periodischen Erscheinungen der Reproduktion der Kiefer an der polaren Waldgrenze. Acta Forestalia Fennica 1(2). 154 p.
Rummukainen, U. 1954. Eräiden kuusenkäpytuholaisten esiintymisestä eri leveysasteilla. Referat: Über das Auftreten einiger Zapfenschädlinge der Fichte auf verschiedenen geographischen Breiten in Finnland. Communicationes Instituti Forestalis Fenniae. 42(4). 21 p.
— 1960. Kuusen siementuhojen runsaudesta ja laadusta. Referat: Über Reichlichkeit und Art der Samenschäden bei der Fichte. Communicationes Instituti Forestalis Fenniae 52(3). 83 p.
Saalas, U. 1949. Suomen metsähyönteiset. WSOY, Helsinki. 719 p.
Saarenmaa, H. 1985a. The role of temperature in the population dynamics of Tomicus piniperda in northern conditions. Zeitschrift für die angewandte Entomologie 99: 224–236.
— 1985b. Within-tree population dynamics models for integrated management of Tomicus piniperda (Coleoptera, Scolytidae). Seloste: Pystynävertäjän lisääntymiskauden populaatiodynamiikkamallit. Communicationes Instituti Forestalis Fenniae 128. 56 p.
— 1987. Tuhohyönteisten ja sinistymän esiintyminen myrskyn kaatamissa puissa Lapissa 1983–86. Summary: Insect attack and blue stain in windthrown trees in Lapland 1983–86. Folia Forestalia 696. 18 p.
— 1989. Eläinten aiheuttamat metsätuhot Lapissa. Abstract: Damage by animals in the forests of Lapland. In: Saastamoinen, O. & Varmola, M. (eds.). Lapin metsäkirja. Acta Lapponica Fenniae 15: 125–134.
— , Heliövaara, K. & Väisänen, R. 1989. Tuhohyönteisten ja sinistymän esiintyminen myrskyn kaatamissa puissa Urho Kekkosen kansallispuistossa. Summary: Occurrence of insects and blue stain in windthrown trees in a national park in northern Finland. In: Poikajärvi, H., Sepponen, P. & Varmola, M. (eds.). Tutkimus luonnonsuojelualueilla. Research activities on the nature concervation areas. Folia Forestalia 736: 66–75.
Siitonen, J. 1993. Lehtikuusen hyönteistuholaiset Suomessa. In: Valtanen, J., Murtovaara, I. & Moilanen, M. (eds.). Metsäntutkimuspäivä Kajaanissa 1992. Metsäntutkimuslaitoksen tiedonantoja (in print).
— & Nikula, A. 1990. Lapinmyyrän puustolle aiheuttamat tuhot Länsi-Lapin ojitetuilla soilla. In: Varmola, M. & Katermaa, T. (eds.). Metsänparannus. Metsäntutkimuspäivät Rovaniemellä 1990. Metsäntutkimuslaitoksen tiedonantoja 362: 56–61.
Sainio, P. 1955. Hirven talvisesta ravinnosta. Summary: On the feeding of elk in winter. Silva Fennica 88. 24 p.
Tenow, O. 1975. Topographical dependence of an outbreak of Oporinia autumnata Bkh. (Lep., Geometridae) in a mountain birch forest in Northern Sweden. Zoonomie 3: 85–110.
Vitikka, P., Posio, H. & Saarenmaa, H. 1991. Hyönteistuhoriski keinotekoisessa ylispuiden kelouttamisessa. Summary: Bark beetle damage in conjunction with artificial snag production in Finnish Lapland. Metsäntutkimuslaitoksen tiedonantoja 378. 32 p.
Weslien, J., Annila, E., Bakke, A., Bejer, B., Eidmann, H. H., Narvestad, K., Nikula, A., & Ravn, H. P. 1989. Estimating risks for spruce bark beetle (Ips typographus (L.)) damage using pheromone-baited traps and trees. Scandinavian Journal of Forest Research 4: 87–98.

Forest damage in northern Finland in 1992

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Abstract

The article is a review of fresh cases of forest damage reported during 1992 in northern Finland and an assessment of the state of earlier years' damaged areas.

Introduction

The state of the forests in northern Finland appears to have further improved in 1992 with respect to the needle losses of 1987 and the *Gremmeniella* dieback epidemic which continued up to and including 1988 (Kaitera & Jalkanen 1992). During the congenial growing seasons of the years 1988–1990 the enhanced resistance of trees, on the one hand, and the impeding of multiplication and spreading of fungi, on the other hand, have resulted in an overall improvement in the state of health of forests in the region. The area covered by the "Salla forest damage" consists of less than 2000 ha of forest afflicted by dieback and canker fungus of pines (*Gremmeniella abietina* (Lagerb.) Morelet) of which only a few hectares is so severely damaged as to warrant regeneration measures (Jalkanen & Kaitera 1992).

An overall picture is beginning to form of the state of the forest damage on the hillsides of western Lapland (Jalkanen 1992a). It is still not clear, however, how many of the afflicted trees on Levi fell, for instance, will die (Jalkanen & Närhi 1993). What is absolutely clear is that the phenomenon in question is a typical case of red belt, which was reported elsewhere in the world already last century, and that airborne impurities have not contributed to its occurrence. The forest damage on the slopes of Levi fell was also inspected in compliance with the legislation pertaining to the prevention of insect and fungal damage together with representatives of Lappi forestry board (Hyppönen & Nikula 1992).

Climatic peculiarities of 1992

The year 1992 began with mild temperatures and continued especially so through February and March. April, on the other hand, was particularly cold throughout (even day temperatures stayed below zero).

May and June were unusually sunny and included the longest ever recorded period in northern Finland of no rain (23 days). It was during this period that the northernmost parts of Finland were the warmest in all of Europe. And then, only a little over a week later, these regions got 20 cm of snow.

When the rains began in July, they lasted for the rest of the growing season. All water systems in Finnish Lapland rose above the normal spring flood limits in August–September. A lasting cover of snow came exceptionally early (October 8) and the snow falls were exceptionally heavy. The temperatures for October were clearly below normal and without spells above zero. November and December were slightly warmer than average with a few spells above-zero and some rain. Since the first cover of snow came down forming a thick layer, the ground was incompletely frozen at the end of the year. On the other hand, the snow layer had melted from below owing to heat released by the soil.

Abiotic phenomena and damage caused by abiotic agents

The year 1992 was characterised by exceptional weather combinations which can be assumed to have acted upon the state of health of at least the more sensitive trees. The tops of birches and several shrub species were observed to have suffered from the warm month in spring and the extremely cold April that followed. Already in March birches were observed to be almost on the point of bud burst. Such shoots were damaged by the cold of April (Jalkanen 1992b). This was especially common in the fertilised yards of houses, but elsewhere as well birches and many indigenous and exotic ornamentals and other plant species such as raspberry dried up and some lost all of their above-ground shoots. The root systems remained intact.

The lack of rain at the beginning of the growing season did no lead to drought. On the contrary, the moisture from the winter snows sufficed even on sandy soils until mid-summer at which time the rains began. Sunny days and an abundance of solar radiation helped the photosynthesis and energy production of trees which are so vital for trees in the building up of resistibility.

Owing to continuous rainy weather, the leaching of nutrients must have been above normal at the same as soil pores contained more water than normally. This resulted in the slowing down of root functions. Towards the end of the summer, yellowing occurred in the foliage in the top parts of the crowns of birches and the inner, more shaded parts of crowns along their entire length. Both phenomena were exceptional and premature (Jalkanen 1992c). Since no sub-zero night temperatures were recorded in Lapland before September, the said yellowing that took place in August was not associated with autumn colours. In fact, autumn colours were about a week behind their normal schedule, after mid-September. Trees were partly green

well into October when the frosts began. The reason for the yellowing of birches is probably partly attributable to the trees' energy and nutritional status following the slowing down of root functions, the leaching of nutrients and extremely low photosynthesis rates. Continuous rain meant high cloudiness percentages. And considering that there were a lot of thunder storms and thunder clouds one can safely guess that the energy status of trees was in a bad way – there were days in August that could just as easily have passed for nights.

The poor state of the trees had been further debilitated by both their root systems being in unfrozen soil when the snow came down (this will have resulted in above-normal respiration through the roots and thereby to loss of energy) and the sudden arrival of winter weather on October 8. Many deciduous trees and shrubs still carried green foliage. Even now (in early 1993) many trees continue to retain some of their leaves because of lack of time for the formation of the abscission zone at the base of the leaf stalk. These leaves have been dried up by the winter's frosts and may stay on for a long time yet. For the trees, this has meant loss of the nutrients and high-energy compounds bound to the leaves. It remains to be seen whether frost damage has also taken place. All in all, one can only speculate as to the effects in 1993 of the end of the summer's weather peculiarities in northern Finland which differed greatly from the situation in southern Finland. Shortage of energy and possible damage by low temperatures may be reflected in delayed initiation of growth in the summer of 1993. The extent of damage visible during the summer of 1993 will, of course, depend on the climatic conditions of the winter of 1992/1993 and the spring of 1993 (e.g. the continuous stormy winds of December 1992 – January 1993).

The yellowing of the old needle age classes of pine (considered to be a good indicator of the energy status of trees) was measured in August of 1992 to apply to an average of one needle age class; this is the long term average for unchanging conditions (Jalkanen 1992c). The extent of needle yellowing in August is influenced by the kind of summer as well as by the number of needle age classes the tree has as compared to a long-term optimum. The situation in the summer of 1992 began to resemble that before the 1987 needle loss phenomenon when pines had 4–5 needle age classes.

Increasing investments have been made in northern Finland to measure airborne impurities. The privately set up station for measuring gaseous sulphur in Salla is in the middle of the "Salla forest damage" area; it clearly indicates that Salla is the recipient of low concentrations of sulphur dioxide. Since the station became active in 1989, the normal background value (4 μg SO_2/m^3 of air) has been exceeded in less than 20 % of the measurement periods. During the past year there have been noticeably less of these excess values (Huttunen *et al.* 1992). The sulphur dioxide and especially ozone concentrations recorded at Sevettijärvi have been considerably higher than those at Salla

(Jurvelin *et al.* 1992). This supports the understanding that the eastern and north-eastern parts of Inari get the main part of the deposition reaching Finland from the Kola Peninsula regardless of the indicator used (Kauhanen & Varmola 1992).

Damage by fungi

Snow blight (*Phacidium infestans* L.) was abnormally abundant as a result of the delay in the melting away of the cover of snow following the cold April. The same applied to the fungus *Lophophacidium hyperboreum* Lagerb. The thick layer of snow that arrived in the autumn promises widespread occurrence of snow blight damage.

From the standpoint of the fungus *Lophodermella sulcigena* (Rostr.) v. Höhnel the dryness of the early summer prevented the release of spores to such an extent that the development of pine needles managed to proceed beyond their most rapid stage of growth. This saved pines from infection, and thus the needle cast epidemic that had begun in 1990 and extended further in 1991 would appear to be on the decline. It must be admitted, however, that partly because of the delay in the appearance of the disease's symptoms following the cool midsummer and partly because of lack of monitoring resources, we do not have a comprehensive picture of the extent of infections during 1992. There was no sign of *Lophodermium seditiosum* Minter, Staley & Millar, a fungus that kills needles of all ages, that had been observed to occur in southern and south-western Finland during the summer of 1992. Neither has this species been observed previously in northern Finland.

Shoot dieback caused by *Gremmeniella abietina* appears to have gained in strength again. Shoots formed in 1991 and killed by this fungus were observed throughout Lapland and especially in western Lapland. More detailed examination of the damage caused revealed that the shoot dieback attributed to this fungus in northern Lapland was mainly something else. It appeared to be limited clearly to those 1991 shoots that had at their base a small, developmentally retarded, unopened cone formed in 1990. Thus, the damage would appear to be physiological by nature and explained by energy having been used to nourish the cone and ripen the seeds at the expense of the shoot. A corresponding situation was observed to apply in the early 1980's (Jalkanen 1985). Weakened shoots may have been killed by frost, for instance.

Although the summer was wet from July onwards, it was surprising to note that rust fungi were not present to any remarkable extent. It was obvious that the pine shoot rust fungus (*Melampsora pinitorqua* (Braun) Rostr.) normally contaminating pines in the early summer could not spread because of the dry weather. This is why the fungus also failed to rise to its normal level in aspens at the end of the summer. But a really tough nut to crack was presented by the abnormally

low-key presence of birch rust fungus, *Melampsoridium betulinum* (Fr.) Kleb. Even the rains mid-way through the summer failed to promote the spreading of the disease even though it had been plentiful a year earlier. Likewise, the other common rusts (except perhaps for *Coleosporium* spp.) were lacking.

Scots pine blister rust (*Peridermium pini* (Pers.) Lev.), the cause of major concern because of the damage it caused in young stands of pine on Lapland's barren heathland sites in previous years, continued producing spores. It is, however, difficult to demonstrate any variation in its activeness from year to year simply on the basis of spore production. A more accurate picture would require detailed examination of the infection years; for the present, no funds are available for this purpose.

Damage by fauna

Just as with fungi, all was quiet on the animal front as well. The populations of *Diprion pini* L. apparently collapsed from the 1991 summer's level when they extended all the way to the Arctic Circle; these insects were not observed in any great numbers in southern Lapland in the summer of 1992. An interesting (though unimportant because of the insignificance of larch) species *Nematus erichsoni* Hart. continued to damage stands of larch and individual trees; this insect can rise to significance within individual stands of larches. In northernmost Lapland a species of *Hymenoptera* caused local defoliation of willows. Willow was also afflicted by a leaf-eating species of *Hymenoptera* that caused local defoliation of willows for instance in SW Lapland so that these places resembled the aftermath of chemical defoliation treatments.

The previous years' more abundant populations of *Eriocrania sparmanella* Bosc. and aphids feeding on aspen collapsed during the summer of 1992. Serious cases of pine aphid (*Pineus pini* Macquart) attacks were reported.

The reduced amounts of timber being stored at the roadside during the summer months and the lack of wind-thrown trees probably led to a marked reduction in the increase in numbers of bark beetles and thereby counteracted damage to standing trees by bark beetles (*Tomicus* spp.). Another factor hindering multiplication in numbers in piles of timber was the continuous rains that kept the timber wet.

According to the latest statistics available, damage to forestry by moose (*Alces alces* L.) fell by a third in 1992 in comparison to the previous year. Moose damage claims in Lapland were also less in terms of area.

A rare occurrence was the 37 000 hectares area of birch damaged by *Epirrita autumnata* Bkh. in the vicinity of the Porttipahta reservoir (Kemppi 1992). The previous significant case of damage by this species

(covering over 250 000 hectares) occurred in the years 1965–1966. This time the damage caused is significant because it took place in the middle of commercial forestry land and surrounded by coniferous forests. Extra resources have to be procured to monitor this incident because there are signs that the moth will be around in the summer of 1993 as well.

References

Hyppönen, M. & Nikula, A. 1992. Levin metsätuhon arviointi metsän hyönteis- ja sienituhojen torjuntalain kannalta. Mimeograph, 22.6.1992. 3 p.

Huttunen, S., Tikkinen, S., Bäck, J., Lamppu, J. & Manninen, S. 1992. Ilman rikkidioksidipitoisuudet, puiden vaurio-oireet ja luppojen rikkikertymät. Abstract: Sulphur dioxide concentrations in the air, tree injury symptoms and sulphur accumulation in needles and Bryoria species. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland Forest Damage Project. Interim Report. Metsäntutkimuslaitoksen tiedonantoja 413: 136–141.

Jalkanen, R. 1985. Die-backs of Scots pine due to unfavourable climate in Lapland. Aquilo Series Botanica 23: 75–79.

— 1992a. Metsävauriot tunturien rinteillä. Ympäristökatsaus 1992(9): 9–10.

— 1992b. Miksi lehtipuut ovat kuivalatvaisia. Lapin Kansa 26.6.1992. p. 2.

— 1992c. Pimeä kesä näkyy männyn neulasten kellastumisena. Pohjolan Sanomat 28.8.1992. p. 2.

— & Kaitera, J. 1992. Versosurma Itä-Lapissa. Abstract: Damage caused by Gremmeniella abietina in eastern Lapland. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland Forest Damage Project. Interim Report. Metsäntutkimuslaitoksen tiedonantoja 413: 215–226.

— & Närhi, P. 1993. Red belt phenomenon on the slopes of the Levi fell in Kittilä, western Lapland. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 55–60.

Jurvelin, J., Hillamo, R. & Virkkula, A. 1992. Ensimmäisiä ilmanlaadun mittaustuloksia Kirakkajärveltä. Abstract: First results of air quality measurements at Kirakkajärvi. In: Kauhanen, H. & Varmola, M. (eds.). Itä-Lapin metsävaurioprojektin väliraportti. The Lapland Forest Damage Project. Interim Report. Metsäntutkimuslaitoksen tiedonantoja 413: 18–24.

Kaitera, J. & Jalkanen, R. 1992. Disease history of Gremmeniella abietina in a Pinus sylvestris stand. European Journal of Forest Pathology 22: 371–378.

Kauhanen, H. & Varmola, M. (eds.) 1992. Itä-Lapin metsävaurioprojektin väliraportti. The Lapland Forest Damage Project. Interim Report. Metsäntutkimuslaitoksen tiedonantoja 413. 269 p.

Kemppi, E. 1992. Tunturimittarituhot Keski-Lapissa vuonna 1992. Mimeograph. Metsähallitus, Kiinteistöpalvelut, Rovaniemi 14.12.1992. 3 p.

Exceptional April frost injury in Sitka spruce plantations

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Abstract

Extensive dieback in plantations of Sitka spruce *Picea sitchensis* (Bong.) Carr. and to a lesser degree in plantations of other coniferous species from the northwestern North America was observed in Denmark in the spring 1991. No injuries to European coniferous species were found. The bark and the cambium of stems and branches were either damaged or killed and leaders and branches had withered. The injuries were caused by the combination of exceptionally high temperatures in March and in the first half of April followed by a short period of unusually strong frost. The injuries observed were identical to injuries recorded in 1938 in a similar situation.

Introduction

Beginning just after April 20th, 1991 an extensive dieback took place in conifer plantations in most parts of Denmark and, in a few cases, in nurseries.

Particularly species from the northwestern North America were affected, mainly Sitka spruce (*Picea sitchensis* (Bong.) Carr.), but also noble fir (*Abies procera* Rehd.), lodgepole pine (*Pinus contorta* Doug.), and, rarely, Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco). Injuries to Japanese larch (*Larix kaempferi* (Lamb.) Carr.) and hybrid larch (*L.* x *eurolepis* Henry) were observed in a few cases, but no injuries to European coniferous species were found (Yde-Andersen & Koch 1991).

Similar injuries with a corresponding area of distribution have been observed only once before in Denmark, namely in 1938 (Ladefoged 1938, Thomsen 1939, Bornebusch & Ladefoged 1940), and similar injuries to Sitka spruce have been observed in northern and western Scotland in 1981 (Redfern 1982).

Material and methods

From the end of April and during spring and summer 1991 numerous injured Sitka spruce plants from forest districts in nearly all parts of

Denmark were received by both institutions for diagnosis. They were examined for pests and biotic as well as abiotic diseases.

From May to September 1991 visits were paid to several forest districts in various parts of Denmark, and samples were taken for examination in the laboratories. At the end of June 1991 two provenance experiments of Sitka spruce planted in 1988 were examined. Both experiments comprised 19 "Danish", one Scottish (probably originally from Queen Charlotte Islands) and one Queen Charlotte Islands provenance.

In June–July 1991 questionnairies were sent to all the forest districts in Denmark. The aim was to find out when the injuries had taken place and to get information about the area, distribution, exposition, age and provenances of the affected plantations. In the autumn 1992 additional observations were made in injured plantations.

Results

Withering was observed in a few cases immediately after the 20th of April and more generally from the end of April. Withering, discolouration and needle loss occurred during the summer nearly all over the country but it was most widely distributed in the western part of Jutland. At least 250 plantations were injured (Christensen 1991). Injuries occurred in plantations established in the spring 1991 as well as in older plantations of up to 3–4 meters in height. No injuries, however, were found in pole-stage crops or older stands.

Injuries were not confined to plantations on cold localities. On the contrary, serious injuries were widespread in newly established as well as in older plantations on sheltered and warm localities and in plantations under shelterwood.

In 1991 plantations with injuries, the seedlings had grown in nurseries and been lifted a short time before planting out. In general, the quality of the seedlings was good, but their development was advanced, for which reason planting out took place immediately after the plants had been lifted and before the 20th of April.

In most 1991 plantations with no injuries the plants had either been lifted in the nurseries at the beginning of April, kept in paper bags and planted out after April 20, or had been cold stored since December 1990 and planted out either before or after April 20.

In older plantations withering began at the same time in May–June as in the new plantations but it continued during the summer. In older affected plantations the percent of injured trees varied from nearly all to few scattered groups of or single trees.

Injuries were observed in plantations with "Danish" provenances and in plantations with provenances from Queen Charlotte Islands. Alaskan provenances were uninjured (Nielsen 1991).

In 1991 plantations withering of the leaders and the branches had taken place in some instances before or just after flushing, in others

when the shoots were brush-shaped, or after the elongation of the shoots had begun. However, the roots and the lower branches, which had been covered by soil at planting, were undamaged (Fig. 1a). Most often no wood formation had taken place in the above ground parts of the plants and the bark was brown and dry. The new as well as the older needles were shed during spring and early summer.

In the older plantations withering started at the same time as in the new plantations but proceded during the summer (Fig. 1b). The affected trees could be divided into two main groups: plants with injuries to the leaders and the upper branches and plants with injuries only in the middle part of the crown. Regardless of where the injuries occurred, the inner bark of the stem in the lower green parts of the crown was nearly always brown to orange mottled. However, immediately above the ground and in the roots no injuries of bark and no abnormal wood formation were observed.

The first main group comprising plants with injuries to the leaders and the upper branches could be further divided into three subgroups.

The first subgroup comprised plants of which the leaders and the upper branches had died in the spring during flushing or just after and stood without needles in the late summer. In these plants the stem-bark in the upper part of the crown was usually sunken, brown and dry. Also the cambium was discoloured, and no wood formation had taken place in 1991.

The second subgroup comprised plants of which the leaders and the upper branches had died at a later time. In some cases only the inner bark was brown to orange mottled whereas the outer bark appeared to be normal (Fig. 1c). In most instances brownish wood had been formed in 1991 immediately outside the normal 1990 annual ring, and in some cases the brownish ring was surrounded by normal wood. The brownish ring, which can be mistaken for a normal annual ring, consisted of abnormal, usually larger, thinner walled cells of much more irregular shape than normal wood cells (Fig. 2).

In the living stem bark immediately below the dying and dead branches necroses occurred. They were most often elongated with cracks and resin flow (Fig. 1d) but sometimes occurred as patches. The necroses were particularly conspicuous in the late summer. While no wood formation had taken place in 1991 on the northern side, wood formation on the southern side was often with normal but brownish ring at the beginning of the annual ring (Fig. 1e). Fructifications of bark-inhabiting fungi, either *Pezicula livida* (B. & Br.) Rehm or *Phomopsis conorum* (Sacc.) Died., were consistently found in the necroses.

The third subgroup comprised plants in which the leaders' and upper branches' green shoots had wilted late in the summer (Fig. 1b). In these plants the inner bark was brown to orange mottled, whereas the outer bark appeared normal. Wood had nearly always been formed in 1991 consisting of a brownish ring surrounded by normal wood.



Figure 1a–e. **a)** Sitka spruce planted in autumn 1990 and damaged by frost in April 1991. To the left, plant showing damage before flushing and with a few living lower branches which had been covered with soil at the plantation. To the right, plant showing damage after flushing. In both plants no injuries occurred in the root collar and the roots. In the upper parts of the plants in 1991 either no wood formation had taken place or the wood formation had started with the formation of parenchymatic cells (frost ring). 17.6.1991. **b)** To the right, Sitka spruce plant damaged by frost in April 1991. After normal flushing withering took place in the beginning of July. In the 1991 annual ring a frost ring was formed immediately outside the 1990 annual ring. To the left, undamaged Norway spruce plant and behind a Sitka spruce plant withered just after flushing. 3.7.1991. **c)** Stem of 7–8 year old Sitka spruce with only a few branches damaged by frost in April 1991. The cut in the bark shows the brown discolouration of the inner bark. 3.7.1991. **d)** Bark nekrosis on the 1989 shoot of Sitka spruce plant. In the left hand side of the shoot bark and cambium are killed, and cracks are found between dead and living bark. 13.9.1991. **e)** Cross section of the 1989 shoot of a Sitka spruce plant showing bark necrosis. On the north side bark and cambium are killed; the necrosis is surrounded by callus formation. In the 1991 annual ring on the south side a frost ring (light-dark) is found.13.9.1991.

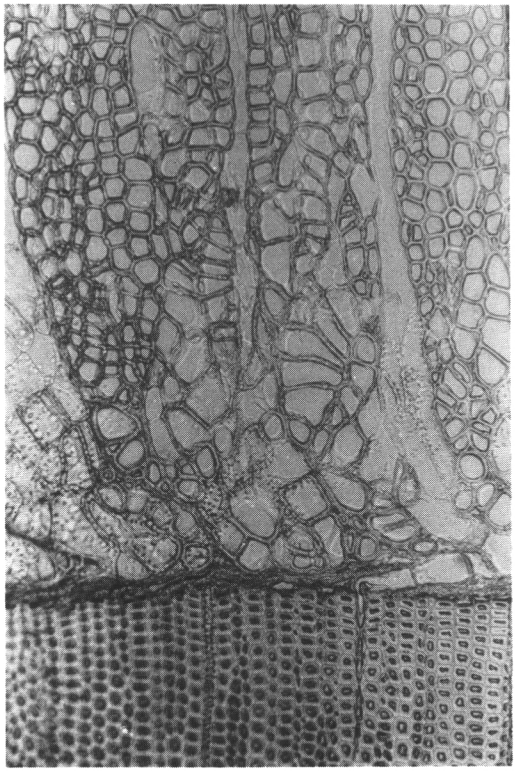

Figure 2. Cross section of a part of a frost ring from an about 10-year-old Sitka spruce plant. In the bottom, normal 1990 late wood followed by a thin, brown layer of collapsed, dead cells. Subsequently a layer of large, thin-walled, irregular, parenchymatic cells, and in the upper part normal wood cells. 2.7.1991.

The second main group comprised plants with injuries in the middle part of the crown and with either living or wilting leaders and upper branches. In these plants the stem bark and the wood formation in the green tops appeared to be normal, but swellings occurred immediately above the damaged middle part. In the middle part bark and wood injuries occurred.

The attacks by the pine bark beetle (*Pityogenes chalcographus* L.) observed in 1938 (Thomsen 1939) in damaged and slightly damaged plants resulting in additional mortality were not found in 1991.

In the autumn 1992 additional observations were made in affected plantations. The observations revealed that in most of the plants injured in April 1991 normal flushing had taken place in 1992 from the undamaged lower parts and 1–3 strong leaders had arisen.

Discussion

The injuries observed in 1991 are identical to the injuries recorded in 1938 (Ladefoged 1938). In April of both years the bark and cambium were killed or damaged resulting in no wood formation at all or in the formation of a frost ring immediately outside the 1937 and 1990 annual ring, respectively. Furthermore wilting and discolouration of the shoots and shedding of new as well as old needles was observed in both years. The injuries differed from "normal" late frost (radiation frost) injuries, which usually only affect swelling or bursting buds and new shoots, and in which a prospective frost ring is situated on the outside of the normal spring wood.

Neither in 1938 nor in 1991 did the distribution of the injuries in the forests and plantations follow the normal pattern for spring frost injury. Thus, in both years serious injuries were widespread in plantations on sheltered and warm localities and in plantations under shelterwood.

In 1938, the March mean temperature in Denmark was 6.0 °C compared with the normal 1.6 °C, the highest mean temperature in March since the beginning of the regular temperature measurements in 1874. The maximum temperatures in March were 9 °C to 18 °C. In the first half of April the temperatures usually were above normal, and the highest maximum temperatures, 13–17 °C, happened April 12–14. However, a storm from the north-west carried cold air over the country resulting in a fall in temperature on April 17. This was most marked in the period 18–21 April with minimums of about –9 °C (Maanedsoversigt ... 1938–1956).

In the years from 1939 to 1990 in March and April no similar fluctuations in temperature have taken place (Maanedsoversigt ... 1938–1956, Ugeberetning ... 1957–1987, 1988–1991).

In 1991, the March mean temperature was 4.2 °C, i.e. 2.6 °C above normal. In the first half of April the temperatures usually were 2–6 °C above normal, and the highest maximum temperatures, 12–19 °C, happened April 14–15. April 18 however, a storm from the north-west carried cold and dry air over the country resulting in a fall in temperatures and April 18–20 minimums were about –7 °C (Ugeberetning ... 1988–1991).

Thus the weather in March and April in 1938 and in 1991 present strong similarities. In both years an exceptional warm period in March and the first half of April was followed by 3–4 days with unusually strong frost caused by cold air from the north-west (advective frost) in the middle of April.

The distribution of the injuries in 1938 together with the nature of the injuries indicated that the exceptional warm weather in March and in the first half of April gave rise to an abnormal early activity of the cambium, and that the activated cambium was damaged or killed in

the period with strong frost around the middle of April (Ladefoged 1938, Bornebusch & Ladefoged 1940). This view was strongly supported by experiments with artificial cooling for a couple of hours to about –12 °C of branches of Douglas fir in flushing resulting in identical injuries (Bornebusch & Ladefoged 1940).

The conclusion is supported by similar observations in 1991 and supplemented with some new ones. The injuries in 1991 were in a few cases observed immediately after the spell with frost. However, seedlings lifted in the nurseries at the beginning of April, kept in paper bags and planted out after April 20 were not damaged. Also, cold stored plants planted out in the beginning of April and in which the cambial activity had been delayed did not suffer.

The attacks by *Pezicula livida* and *Phomopsis conorum* observed in 1991 and the attacks by pine bark beetles observed in 1938 are considered to be of a secondary nature (Ferdinandsen & Jørgensen 1938–39, Thomsen 1939, Redfern 1982).

All the provenances – which in other respects have been shown to be well suited for plantation in Denmark – were more or less susceptible. A single observation, however, indicates that Alaskan provenances, i.e. more northern provenances in which the cambium presumably is activated at a later time, might be resistant. The observation is in accordance with the observations in a Scottish provenance experiment in which Alaskan provenances showed significantly less damage than more southerly provenances (Redfern 1982). Testing of more northern provenances should therefore be considered.

The common remedy against late frost injury – the use of shelterwood and nurse trees – has shown no positive effect, if anything quite the contrary. The use of cold stored seedlings in combination with late planting will, however, reduce the risk in the year of planting. In the autumn 1992 it could be seen that many seriously damaged plantations would recover completely and just need a cutting of surplus leaders.

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References

Bornebusch, C.H. & Ladefoged, K. 1940. Hvidgranens og sitkagranens dødelighed i hede- og klitplantager i 1938 og 1939. Det forstlige Forsøgsvæsen i Danmark 15: 209–232.

Christensen, P. 1991. April-frostskader i sitkagrankulturer. Udbredelsen. Skoven 91: 465.

Ferdinandsen, C. & Jørgensen, C.A. 1938–39. Skovtræernes sygdomme. Nordisk Forlag, København. 570 p.
Ladefoged, K. 1938. Frostringdannelser i vaarveddet hos unge douglasgraner, sitkagraner og lærketræer. Det forstlige Forsøgsvæsen i Danmark 15: 97–112.
Maanedsoversigt over vejrforholdene. 1938–1956. Det danske meteorologiske Institut.
Nielsen, U. 1991. April-frostskader i sitkagrankulturer. Har proveniens og klon betydning ? Skoven 1991(11): 466–467.
Redfern, D.B. 1982. Spring frost damage on sitka spruce. Report on Forest Research for the year ended March 1982. H.M.S.O. London.
Thomsen, M. 1939. Angreb af Tomicus chalcographus på unge sitkagraner, rødgraner og douglasgraner. Det forstlige Forsøgsvæsen i Danmark 15: 199–208.
Ugeberetning om nedbør m.m. 1957–1987. Månedstillæg. Danmarks Meteorologiske Institut.
Ugeberetning om nedbør m.m. 1988–1991. Månedstillæg. Danmarks Meteorologiske Institut.
Yde-Andersen, A. & Koch, J. 1991. April-frostskader i sitkagrankulturer. Skaderne og årsagen. Skoven 1991(11): 461–464.

Climatic injury as a problem of introduced species in northern Britain

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Abstract

Exotic species constitute a major proportion of the conifer forests of northern Britain. This paper describes climatic problems affecting a number of species and provenances which originate from more southerly latitudes or from different climatic zones. Unseasonal frosts are the most frequent cause of damage to Sitka spruce (*Picea sitchensis* (Bong.) Carr.), the principal exotic species. Winter cold injury is rare and has caused significant damage, to Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melville), on only one occasion in the 20-year period to 1991. On the other hand, alternating periods of unusually cold and mild weather accompanied by strong winds are much more damaging. In Britain's maritime climate, Norway spruce (*Picea abies* (L.) H. Karst.) is affected by a serious condition known as "top dying". Damage is associated with mild, windy winters and may be exacerbated by drought.

Introduction

Forestry in Britain contrasts sharply with that in continental Europe and provides interesting examples of diseases and disorders which are peculiar to our circumstances of plantation forestry, predominantly with exotic conifer species.

At the beginning of this century only 5 % of the land area of Great Britain was forested. Since that time the area under forest has doubled to approximately 2 million hectares – mostly by the formation of conifer plantations on land previously used for some form of agriculture. Because our only native timber-producing conifer, Scots pine (*Pinus sylvestris* L.), is unsuitable for most of the area available for afforestation, large-scale use has been made of conifer species from western North America, continental Europe and Asia. Many grow extremely well. Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is the principal species, comprising 40 % of the conifer plantation area, but other important exotic species are Norway spruce (*Picea abies* (L.) H. Karst.), Douglas fir (*Pseudotsuga menziesii* (Franco) Mirb.), Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melville), lodgepole pine (*P. contorta* Douglas ex Loud.), European larch (*Larix decidua* Miller) and Japanese larch (*L. kaempferi* (Lambert) Carr.).

The British climate is maritime, with generally equable temperatures, particularly in western coastal areas, and this has encouraged use of species and provenances from more southerly latitudes: Corsican pine and Washington provenances of lodgepole pine and

Sitka spruce, for example. Inland areas experience more continental conditions which present a risk, particularly of damage by unseasonal frosts, to this type of material. However, the risk is readily appreciated by forest managers and use of Washington and even Oregon Sitka spruce, as well as tender pines such as *Pinus radiata* D. Don., is generally restricted to southern or western coastal areas of Britain. In inland and northerly areas, the more southerly origins of Sitka spruce are avoided, the most common origin being the Queen Charlotte Islands of British Columbia, Canada. Alaskan provenances have been grown on a trial basis but their slower growth rate is considered to outweigh any superiority in frost hardiness (McRobbie, Fountain Forestry Ltd, personal communication).

In what is generally regarded as a mild climate, it is less readily appreciated that winter weather may also be damaging. The British climate is characterised by variability and windyness (Manley 1952); temperature fluctuations resulting from the interplay of atlantic and continental weather systems, especially in combination with strong winds, can cause dramatic symptoms and major losses.

Unseasonal frost damage to Sitka spruce

In the period of full winter dormancy, temperatures have not apparently fallen low enough to injure Sitka spruce in the 70-year period during which it has been grown on a large scale. Outside this period, damage has been recorded by the Forestry Commission's Pathology Advisory Service in every month except July and August.

In spring, frost damage may take several forms depending on the date and severity of the event. Post-flushing injury is well known and the effects of the frosts of May 1935 are particularly well documented (Day & Peace 1946). Damage is not uncommon in early June.

Sub-lethal damage to extending shoots renders them temporarily flaccid and pendulous. Rigidity is subsequently recovered in this position and resumption of growth the following spring results in distortion. It is possible that while the shoots are flaccid wind may add to the deformation, which may be so extreme that the branch assumes a corkscrew shape.

Sitka spruce is also subject to injury before flushing (Redfern 1982). In April 1981 cambium on the main stems of Sitka spruce in north and west Scotland was injured by frost on the night of 22–23 April, when screen minima as low as –10 °C were recorded. This followed a 4-week period of generally very warm weather with daily maxima as high as 17–20 °C on a number of occasions. Trees up to 5 m tall were affected. Initially, affected trees flushed normally, but those which had been girdled by death of cambium, usually at about the mid-point of the stem, died back during summer. By late summer most trees had formed recovery shoots on healthy stem tissue below the zone of injury. In a provenance experiment, Alaskan provenances were less

severely injured than those of more southerly origin. Similar damage, but on a lesser scale, occurred in late April 1989 after an exceptionally mild winter (Gregory *et al.* 1991).

The earliest autumn frosts can damage late season shoot growth ("lammas" growth) but needles remain vulnerable for much longer and damage has been recorded as late as mid-October. Over the last 20 years it has been most frequent in September. Symptoms are restricted to current-year needles and older needles characteristically escape injury (Redfern & Cannell 1982).

In autumn, needles become more frost hardy as daily minimum temperatures fall below about 8 °C and gradually approach 0 °C, so that in "normal" years needles can withstand temperatures of –5 °C to –10 °C without injury by the time the first frosts occur. However, if frosts of this severity are preceded by warm weather needles will not have become hardy and may be damaged. Clearly the risk of such damage increases with the duration of any period of mild weather in autumn since the likelihood of a frost severe enough to cause injury also increases.

The severity of damage varies with provenance: trees of more southerly origin are more susceptible than those from the Queen Charlotte Islands and Alaska. There is some field evidence that nutrient deficient trees may be more susceptible than those of a higher nutritional status but the results of frosting experiments apparently conflict with this (Jalkanen, personal communication).

Buds on affected shoots generally flush in spring but when damage is severe shoots and buds may die. On surviving shoots, extension growth and needle length may be greatly reduced in the following growing season (Fig. 1).

This type of needle injury was sufficiently widespread and severe to be reported to the Pathology Advisory Service on six occasions during the period 1971–1991 (1971, 1972, 1979, 1986, 1989 and 1991).

Winter cold injury to conifers

In January 1982, the lowest temperatures ever recorded in Britain (–27.2 °C at Braemar) killed a number of species and provenances of southerly origin (Redfern & Rose 1984). Corsican pine was the principal commercially important species affected but there was minor damage in Douglas fir and lodgepole pine.

Injury involved death of phloem and cambium on the lower stem rather than death of shoots or foliage. Girdled trees died throughout 1982, with some surviving until 1983. Partial damage to phloem and cambium caused the formation of longitudinal lesions, some of which were sufficiently extensive to cause a marked growth reduction in 1982. Gremmen (1961) described similar damage to Corsican pine in the Netherlands in February 1956.

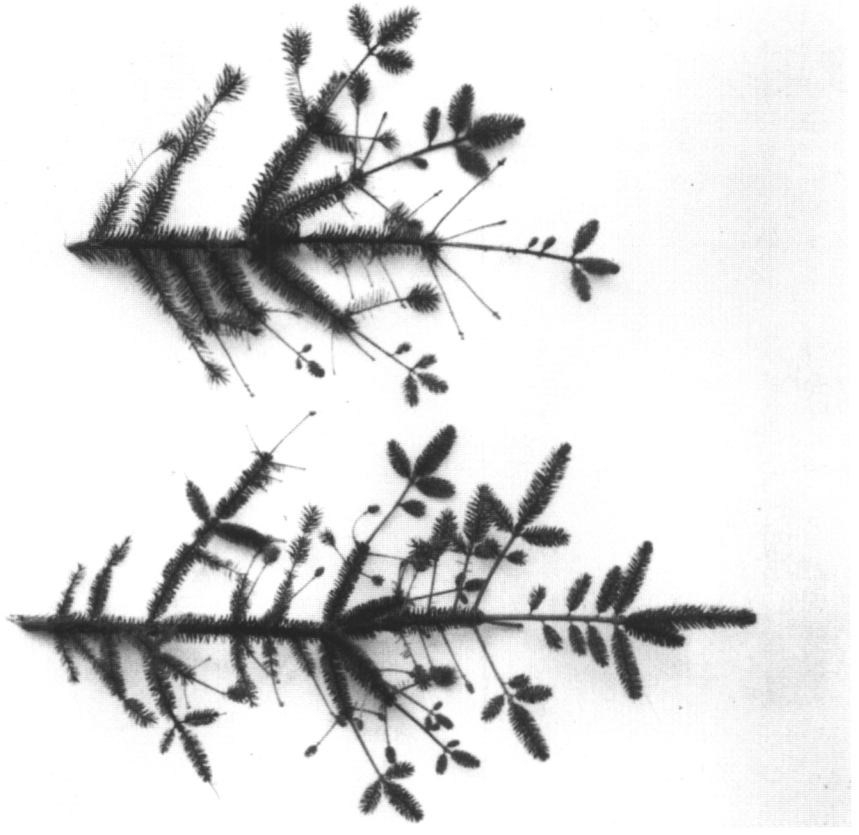

Fig. 1. Effect of frost on 10 September 1986 on shoot growth in the subsequent year. Note shedding of 1986 needles, death of some 1986 shoots and poor 1987 extension growth on some surviving shoots. Photograph 13 October 1987.

Damage associated with temperature fluctuations and wind

In spite of the southerly origin of some species grown in Britain, winter cold seems to be less important as a cause of injury than fluctuating temperatures combined with wind. During winter 1978–79, lodgepole pine suffered widespread foliage browning and shoot death in North Scotland; a phenomenon possibly related to damage in Canada known as red belt (Redfern *et al.* 1980, Robins & Susut 1974).

Similar injury was seen on a wider range of conifers in 1984 and 1986. In the first case it occurred on older crops, principally Sitka spruce, at high elevation in North-West England and West Scotland (Redfern *et al.* 1987b). Damage consisted of foliage browning and shoot death, which was concentrated typically in a zone of variable extent below the upper few whorls of affected trees. It was widespread and occasionally dramatic but not generally serious.

In 1986 damage was again observed on a number of species at high elevation in West Scotland but this time it mostly involved trees less than 10 years old and was particularly serious on Sitka spruce planted the previous year (Redfern *et al.* 1987a).

A study of weather patterns strongly suggested that on both occasions damage was caused by alternating periods of unusually cold and mild weather accompanied by strong winds. The phenomenon may be essentially one of winter desiccation.

Top dying of Norway spruce

This is the most serious climatic and physiological disorder of a commercially important exotic conifer in Britain, and seems also to be caused by excessive moisture loss in winter. It differs from the problems already described on exotic species in that it is associated with a change of climatic region, from a continental to a maritime climate, rather than a change of latitude.

The condition was first described in Britain by Murray (1954, 1957) but, apart from work by Diamandis (summarised by Diamandis 1979) it has been little studied. The principal characteristics of the condition, drawn from this literature and the experience of the Pathology Advisory Service are:

1. Basipetal browning of current year's needles usually occurs during winter and early spring, but may begin as early as late summer.
2. Growth reduction may be concurrent with browning or may even precede it.
3. The condition most commonly affects pole-stage crops.
4. It is typically initiated by thinning or the removal of side shelter.
5. It is most severe at crop edges but frequently spreads among susceptible individuals throughout the crop; small, isolated stands and narrow belts are particularly vulnerable.
6. It is associated with warm, windy winters and possibly exacerbated by drought.
7. It is most common in drier, eastern parts of Britain.

Top dying is the only climatic disorder in Britain which, since it is associated with thinning and the removal of adjacent stands, constrains crop management. Murray (1957) recommended that thinning should be early, light and frequent. The treatment of affected crops presents a dilemma since the harvesting of damaged trees in salvage thinnings is likely to exacerbate the problem. Nevertheless this approach is probably preferable to losing the produce represented by dead trees, or to premature clear felling.

References

Day, W.R. & Peace, T.R. 1946. Spring frosts. Forestry Commission Bulletin 18 (second edition). HMSO, London. 111 p.

Diamandis, S. 1979. 'Top-dying' of Norway spruce, Picea abies (L.) Karst., with special reference to Rhizosphaera kalkhoffii Bubák. Evidence related to the primary cause of 'top-dying'. European Journal of Forest Pathology 9: 183–191.

Gregory, S.C., MacAskill, G.A., Redfern, D.B. & Pratt, J.E. 1991. Report on Forest Research 1990. HMSO, London. p. 47.

Gremmen, J. 1961. Vorstschade aan Corsicaanse Dennen. Nederlands Bosbouwtijdschrijft 33: 328–332.

Manley, G. 1952. Climate and the British scene. Collins, London. 382 p.

Murray, J.S. 1954. Two diseases of spruce under investigation in Great Britain. Forestry 27: 54–62.

— 1957. Top dying of Norway spruce in Great Britain. Seventh British Commonwealth Forestry Conference, Australia and New Zealand, 1957. Forestry Commission, London. 9 p.

Redfern, D.B. 1982. Spring frost damage on Sitka spruce. Report on Forest Research 1982. HMSO, London. p. 27.

— & Cannell, M.G.R. 1982. Needle damage in Sitka spruce caused by early autumn frosts. Forestry 55: 39–45.

— , Gregory, S.C. & Low, J.D. 1980. Report on Forest Research 1980. HMSO, London. p. 35.

— , Gregory, S.C., MacAskill, G.A. & Pratt, J.E. 1987a. Report on Forest Research 1987. HMSO, London. p. 42.

— , Gregory, S.C., Pratt, J.E. & MacAskill, G.A. 1987b. Foliage browning and shoot death in Sitka spruce and other conifers in northern Britain during winter 1983–84. European Journal of Forest Pathology 17: 166–180.

— & Rose, D.R. 1984. Winter cold damage to pines. Report on Forest Research 1984. HMSO, London. p. 33–34.

Robins, J.K. & Susut, J.P. 1974. Red belt in Alberta. Northern Forest Research Centre, Canadian Forestry Service, Environment Canada, Edmonton, Alberta, Canada. Information Report NOR-X-99. 7 p.

Red belts in boreal forests

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Abstract

Recent occurrences of red belts in Scandinavia and western North America are reviewed. Red belts are a particular type of winter frost damage to trees which occur in certain localities in some parts of the world. Typically the injury appear as narrow bands or belts at specific elevations above valley bottoms. Symptoms are described as reddening of foliage, later shedding of needles of conifers, and injured buds and shoots, if not covered by snow. The dominating opinion among cited authors is that sudden temperature changes is the inciting cause of red belts, usually in connection with inversion situations. In the following spring, affected trees may show anomalous shoots or leaves, diebacks, and reduced growth.

Introduction

Red belts are a particular type of winter frost damage to trees in certain topographic localities, causing reddening of foliage of conifers, becoming spectacular in late winter or early spring (Boyce 1961). Typically red belts appear as more or less well delimited horisontal stripes or broader bands at specific elevations in valleys and mountainsides, less commonly on forest areas in valley bottoms.

The occurrence of a particular type of frost damage in Finland in early spring 1991 (Jalkanen 1992) promted this brief review of red belts.

Symptoms

All tree species within a red belt may be affected. Conifers will rapidly develop a conspicuous reddening of their foliage. Decidious trees may show diebacks later in spring and lack of foliage, or anomalous development of leaves.

Pine needles show bright reddish-brown discolourations, commonly from the tip inward and only in severe cases extending to the base. Current-year shoots are affected first, and with increasing severity more needle-years are hit, and all foliage may become discoloured. Vigorous branches in upper parts of the crown escape injury to some degree, while non-vigorous branches in lower and inner parts of the crown suffer more. Twigs and branches with total discolouration may

still have living buds. However, even when severely affected, pines rarely have complete discolouration of their foliage and all buds killed.

Spruce needles show deep reddish-brown discolourations, from the tip inwards or more often in full length. Discoloured needles are easily dropped, soon leaving affected spruces less conspicuous than pines. Lightly affected spruces may show injury only to the current-year-needles, or to foliage of the last two to three years. Defoliated shoots often have killed buds. Suppressed branches and weakened twigs are commonly more affected and may regularly have their buds killed. Vigorous shoots in the uppermost part of the crown may retain some living needles, and their buds are more likely to survive. Even surviving buds are affected, they may produce dwarfed off-coloured shoots. Severely affected trees may show complete discolouration of foliage and death of all buds. Commonly spruces appear to suffer more injury than pines.

Other conifers, e.g. douglas fir, may show symptoms of similar features, when being present in affected areas.

Birches may suffer severe injury when located in a red belt. The resulting effects are never visible before spring, when normal leafing is due. Trees may then be left naked, or a few living buds may put out abnormal leaves that are distorted, thorn, dwarfed or even larger than usual. Primarily twigs in the outer and upper portions of the crown appear to be affected.

Aspen may suffer death of twigs and branches in the same manner as birch. Distorted leaves are seldom noticed, but abnormal big-sized leaves are often observed the following spring.

Alders are affected in the same way as birch, showing typically disformed leaves produced from surviving but affected buds. When leaves unfold, they may display open areas between veins on one or both sides of the midrib.

Other deciduous trees may show similar effects.

Distribution

Red belts occur in valleys, at certain elevations above the valley bottom, or in hillsides above lakes, or in similar types of topography. They sometimes reoccur in the same locality, and may be found in the lowland, though they are more frequent in mountainous regions. When the injury is slight, only exposed trees are affected, often those located on outstanding ridges along the hillside. When the injury occur in a valley bottom it may be doubt about its origin. However, reliable reports are given also of such type of red belts (MacHattie 1963).

Typical red belts are reported only from a few countries in the world. In western North America they occur in the interior of the coastland, on the lee side of mountain ranges. Red belts are frequently reported

from Alberta, Canada, on the mountain slopes of valleys east of the Canadian Rockies (Robins & Susut 1974).

Scandinavia is another part of the world where red belts have been found regularly. From Norway about 40 occurrences are reported during the last 100 years. However, some occurrences are probably never reported. Most of the described red belts have been found in the south-eastern part of the country, in the upper part of valleys east of the central mountains. These belts, often along both sides of the valley, have been found from Vestfjorddalen in the south-west, to Østerdalen in the north-east. Descriptions are given by Venn (1962), and Libach (1980). Recent occurrences are described by Solberg (1993).

In Sweden red belts appear less frequently. They have all been reported from slopes above waters or rivers. Several large red belts occurred in 1928, in the valleys of Luleå, Råne, Vindeln, and Ljungan (Langlet 1929). These red belts appeared in north-western parts of Sweden, farther north than most occurrences in Norway.

There are hardly any reports of red belts from Finland. In 1991, however, there are some occurring in the north-western part of the country (Jalkanen 1992).

Red belts or similar frost injuries have been reported also from the central European Alps.

Etiology

Important clues to the origin of the red belts may be found in the appearing symptoms. Remaining green foliage that has been covered by snow during winter, indicate the seasonal time of the injury. Sometimes the injury is oriented towards northerly aspects, indicating a contributing effect of wind. Several explanations have been launched. An early theory focused on the fact that fog often appeared in certain altitudes above rivers and lakes. At low temperatures the fog condensed as ice crystals on trees. This hoarfrost was believed to injure needles and twigs when sunshine forced it to vaporize (Schøyen 1909).

In Canadian literature red belts have been accosiated with Chinook winds, the injury usually being attributed to desiccation (Henson 1952). The effect of abrupt temperature rises is stressed (MacHattie 1963).

The concept still in power was published by Langlet (1929). He studied critically all red belts known till then from Norway and Sweden, as well as meteorological data and experiences from the Alps. He concluded that local topography was decisive, in combination with some special weather situations. According to his hypothesis red belts may develop only if the terrain allows cold air to accumulate, either as a cold air pool above a lake or in a valley partly closed by a constriction, or as a cold air river floating slowly down a valley. In a more

continental climate such weather conditions may occur regularly during late autumn to early spring. However, in regions next to the western coasts, mild air from the ocean may blow slowly in over the cold air. If this happens, and the warm air is allowed to settle upon the lakes or rivers of cold air for some days, a sharp transition zone developes between the upper and lower air layers. Through the diurnal cycle, perhaps influenced by changes in air pressure, and inflow or outflow of cold air, this transition zone may fluctuate in altitude. Trees located in areas hit by the resulting alternation between warm and cold air may thaw and freeze repeatedly. Exposed parts of trees, in particular needles and twigs, may experience too quick freezing and thawing, resulting in frost injury. Even very short thawing periods may injure needles if they afterwards are frozen, and the damage increases if the procedure is repeated (Venn 1979).

Meteorological data support the concept that specific weather situations have been present at the time when red belts occurred. Usually a stable high pressure situation with low freezing temperatures are followed by an westerly inbreak of warm air from the ocean. Temperature inversions are noticed in such localities where red belts are likely to occur.

Consequenses

Winter frosts of the type causing red belts may injure forest trees in various ways. The more obvious damage of the foliage is of consequenses for the crown density. Defoliation and loss of assimilatory capasity lead to reduced growth, both in diameter and heigth. Comparison of radial growth after red belting with that before indicates that growth is reduced in proportion to the fraction of foliage killed (Blyth 1953). Pine and spruce need three to seven years to regain their original growth rate (Libach 1980).

Death of buds and dieback of twigs and branches lead to abnormal crown structures. Affected trees may end up with having reduced length of green crowns. Trees putting out new shoots only in the uppermost branch whorls may survive for some months. However, such weakened trees are often killed during the following summer by secondary attack by bark beetles.

In severe cases the frost injury is causing death of trees, which will reduce stand density and affect stand production.

References

Boyce, J.S. 1961. Forest pathology. Third ed. McGraw-Hill Book Company, Inc. New York. Toronto. London. 572 p.

Blyth, A.W. 1953. Reduction of growth in conifers caused by red belts in the subalpine region of Alberta. Silvicultural Leaflet No. 79. 3 p.

Henson, W.R. 1952. Chinook winds and red belt injury to Lodgepole pine in the Rocky Mountain parks area of Canada. Forestry Chronicle 28: 62–64.
Jalkanen, R. 1992. Får Levi i Kittilä en horisontal slalombacke? Skogskadebältena i västra Lappland undersöks. Skogsaktuellt 1992(1): 24–27.
Langlet, O. 1929. Några egendomliga frosthärjningar i tallskog, jämte ett försök att klarlegga deras orsak. Svenska Skogsvårdsföreningens Tidskrift 27: 423–461.
Libach, C. 1980. Frostbelter. Virkning på tilvekst og knoppskyting hos furu og gran. Hovedoppgave ved Norges landbrukshøgskole, Ås. (manuscript).
MacHattie, L.B. 1963. Winter injury of Lodgepole pine foliage. Forest Research Branch Contributions 536: 301–307.
Robins, J.K. & Susut, J.P. 1974. Red belts in Alberta. Northern Forest Research Centre, Edmonton, Alberta. Information Report NOR-X-99. 7 p.
Schøyen, W.N. 1909. Om frostskade paa furuskog. Tidsskrift for Skogbruk 17: 25–27.
Solberg, S. 1993. Monitoring of abiotic diseases in Norway. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in Forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 89–92.
Venn, K. 1962. Frostbelter. En sjelden frostskade i Krødsherad. Norsk Skogbruk 18: 591–594.
— 1979. Winter vigour in Picea abies (L.) Karst. VI. Frost injury to needles of Norway spruce seedlings exposed to experimental freezing during midwinter. Meddelelser fra Norsk Institutt for Skogforskning 35(1). 21 p.

Red belt phenomenon on the slopes of the Levi fell in Kittilä, western Lapland

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Abstract

The occurrence and status of a red belt found on the N-NE slopes of the Levi fell in Kittilä, western Lapland in spring 1991 is described one growing season after its appearance. The long and narrow pine-dominated belt, 176 ha in size was located between 228 m and 320 m a.s.l., the average injury layer being 45 m in height. 39 % of the pines within the injured area, which consisted of a severely injured part in the middle of the red belt and moderately injured area around it, were estimated to have died within the first spring and summer since the injuries occurred.

Introduction

A long, narrow and conspicuously reddish-brown stripe was noticed on the NE slopes of the Levi fell in Kittilä in the spring of 1991. The exceptional colour was produced by the injured needles of Scots pine at a certain elevation up the slope. Minor injuries were noticed on the SE slope of the same fell but not in other directions.

The above mentioned forest injuries are referred to as the red belt phenomenon in the forest pathology literature. The oldest records dealing with the phenomenon date back to the last century (Evenstad 1881, Hørbye 1882) and the early years of this century (Skurdal 1908, Schøyen 1909, Hansen 1921) in Scandinavia and later in North America (Hartley 1912, Melrose 1919). Since the early decades of this century, red belt type winter injuries have been reported continuously both in Scandinavia (Jørstad & Roll-Hansen 1943, Jørstad 1949, Venn 1962) and the United States – Kanada (Henson 1952, Blyth 1953, MacHattie 1963, Robins & Susut 1974, Bella & Navratil 1987, Klein 1990, Schmid *et al.* 1991).

The most relevant hypothesis describing the principal factors was written in the 1920's by Langlet (1929) in Sweden. In his wide and comprehensive work, prof. Olof Langlet summarises all the known red belt occurrences and literature from Scandinavia. None of them is, however, from Finland. As to northern Finland, red belt injuries in 1928 were reported to have occurred in northern Sweden, which indicates that similar damage may have occurred at that time in northern Finland, too. However, there are no written records about red belts in Finland before the year 1991 (Jalkanen 1992).

This paper reports on the 1991 red belt injury on the Levi fell in Kittilä, Finnish Lapland.

Material and methods

The red belt area on the slopes of the Levi fell (67°47'N, 24°52'E) was surveyed in August 1991 starting with one sample plot below and ending with one sample plot above the injured area in each transsect, which were placed across the main countour lines of the slope (and thus across the red belt, too). Depending on the width of the injured area, one or more plots were situated inside the red belt within one transsect and two outside of it (but only one if red belt reached the timber line). The distance between transsects was 500 m and between sample plots 40 m. The sample plot radius was 5.64 m giving an area of 0.01 ha. The total number of sample plots was 123.

An aneroid was used to determine altitudes of the sample plots and at the edges of the injury belt. The distances from soil surface to the injury layer and to the nearest plot were also measured.

All trees with a breast height diameter (DBH) greater than 2.5 cm were included as sample trees and measured for their DBH. The height estimate for the plot was determined from the first sample tree in the direction of the transsect. Age was recorded by examining one dominant tree in every 7th sample plot. Of the total of 1119 sample trees, 445 were pines (*Pinus sylvestris* L.), 71 spruces (*Picea abies* (L.) H. Karst.), 576 birches (*Betula* spp.), 21 aspens (*Populus tremula* L.) and six were other broadleaved species (mainly *Salix* spp.).

Stand density was 910 stems/ha. The average age of the dominant tree species, Scots pine, was 87 years in the western and 120 years in the eastern part of the belt as a sum of age at breast height + 25 yrs. The mean DBHs were 12.6, 8.7, 7.2 and 13.0 cm and the mean heights 9.8, 9.6, 5.7 and 10.1 m, respectively for pine, spruce, birches and aspen.

Each sample tree was examined for the distribution and compass direction of the damage and the extent of injuries within the canopy and foliage, mortality of buds and the quality of new growth in 1991 within the crown, and attacks by *Tomicus* spp. on the main stem. Stand vigour was estimated based on the status of the sample trees.

Results

The main injured area (red belt) was situated on the N-NE slopes of the Levi fell. According to the situation on the sample plots, over two thirds of the plots were oriented to the NE or N. Some minor damage occurred on the SE slope. None of the plots were oriented to the S or SW.

Most of the injuries were located between the contour lines of 245–320 m a.s.l. Thus the injured layer was 75 m high. However, the

western end of the red belt was located clearly lower, at 228–267 m a.s.l., and its average height was only 39 m. On the SE slope of the mountain in Utsuvaara, the red belt was at a level of 285–305 m a.s.l., the injury layer being only seven metres high on the average. Thus, the central parts of the Levi red belt were situated between 260 and 320 m a.s.l., where the average injury layer was 45 m high. The upper edge of the red belt reached the closed alpine timber line only occasionally and mainly NE from Jäkälälaki. In most cases, and especially the western end's large forested areas, which were situated above the red belt, there was no sign of injury in the spring of 1991. Forests remained healthy in appearance along the valley bottom, too. There was no opposite slope.

The total area of red belt was estimated to be 176 ha with a maximum length of about 5 km and maximum width of 450 m. The inner parts of the belt were clearly more injured than the outer ones. The former area, with its severely injured trees, covered 108 ha and the latter one of moderate injuries 68 ha (Fig. 1). The SE slope of the mountain was injured only moderately. No injuries were found on the SW or S slopes of the mountain, where the forests were like those on the NE slope.

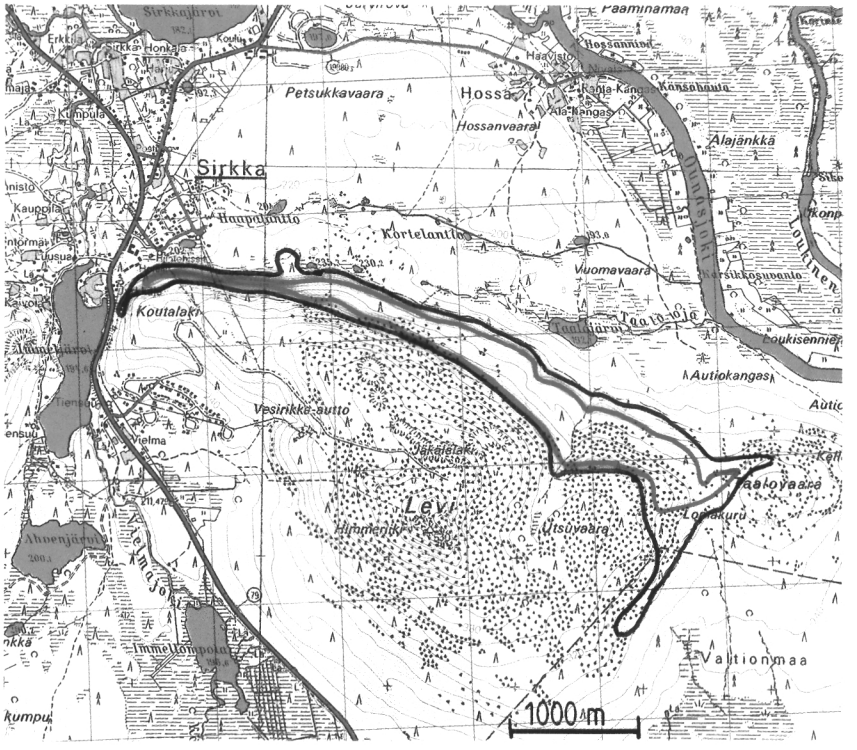

Figure 1. Location of the long and narrow red belt in the Levi fell in Kittilä as seen at the end of the summer of 1991. The trees in the inner part of the area were severely injured.

In the moderately injured area, pine and spruce needles had turned yellow green and in somes cases even exhibited tip yellowing. The buds had stayed alive, flushed and produced normally looking shoots in 1991. Birches had dead shoot tips, but rather normal foliage. The injuries observed were estimated to have no or little effect on tree growth.

In the severely injured area, pine needles from one year old to the oldest ones had turned reddish-brown. These needles seemed to stay longer period in the shoots, whereas most of the grayish-brown spruce needles had been shed as early as in the summer of 1991. Pines had none or just a few new shoots with or without green needles, and these occurred mainly in the top of the crown. Most of the spruces did not flush at all in 1991. The birches had lost most of their branches. Their leaves were abnormal in shape and size occurring only along the main stem and at the base of the thickest branches. Leaves were observed to occur only on adventitious shoots. The injuries were estimated to be so severe that afflicted trees were expected to suffer from severe growth losses or even to die as a result.

Asymmetrical crown injuries were observed on 15 % of the pines and 19 % of the spruces. The trees thus injured were concentrated within the moderately damaged area and especially along the upper edge of the red belt. In all cases, the more damaged side was that facing the main slope (i.e. N or NE). In the lower, western part of the red belt, the more severely damaged side was oriented to the NW. However, most of the trees were evenly injured on all sides. The birches were injured evenly on all sides of the crown.

On the other hand, vertical differences in the extent of injury were very distinct. Especially in the shallowest part and along the edges of the red belt it was either the top or the lower part of the crowns of pines that was injured in the spring of 1991. A smaller tree behind a bigger tree had less injuries. Also trees in topographical depressions were healthier. Branches and small trees that had covered by the snow in the previous winter did not show any symptoms.

Within the red belt, 92 % of the pines showed no signs of attacks by pine shoot beetles to the stems in 1991. Three percent had been attacked 1–10 times and five percent more than ten times.

Pine, the dominant tree species in the Levi red belt, with its reddish-brown needle colour suffered major losses. Within the red belt, 25 % of the pines were uninjured. The proportion of pines exhibiting needle yellowing but without any growth losses was 14 % whereas pines estimated to suffer minor growth losses amounted to 8 percent. Fourteen percent were estimated to incur severe growth losses. All the above mentioned trees were, nevertheless, estimated to survive. The remaining 39 % had been so severely injured that they were expected to die or they had already died at the end of the summer 1991.

Discussion

The long and narrow injured area, reddish-brown in colour, on the N-NE slopes of the Levi fell is a typical red belt damage area (Melrose 1919, Venn 1962). Of the various similarly injured slope forests throughout Lapland in the spring of 1991 (Jalkanen 1992), the Levi red belt was the most impressive of the kind of damage of which is new for Finland but not for Scandinavia. On reading Langlet's (1929) extensive but prease description of the red belt in Sweden in 1928, one has the sensation of being in the middle of the Levi red belt. However, there may be a need for a revision of Langlet's hypothesis in the light of today's terminology and knowledge. This discussion on the possible factors involved in the red belt phenomen and described as a red belt had to be started especially due to the fact that researchers in the United States (e.g. Klein 1990) and Canada (e.g. Robins & Susut 1974, Bella & Navratil 1987) have never referred to any of the Scandinavian articles dealing with the phenomenon since 1881 (starting from Evenstad 1881).

According to Langlet's (1929) hypothesis, temperature inversion and rapid temperature fluctuations typical for boreal zone in winter are the main contributing factors. During a spell of strong inversion, the Sodankylä observatory of the Finnish Meteorological Institute measured the strongest inversion ever recorded in Finland on the morning of the 4th of February 1991. The temperature was nearly 30 °C lower at 2 metres above the soil surface than 240 m above it (Finnish Meteorological ... 1991).

The future of the forests in the Levi red belt is uncertain. Some of the trees have already died, and some will die during the next few years. The proportion of injured trees that will survive and recover cannot be reliably estimated earlier than at the end of the second or third growing season after the injury although most affected stands have been reported to recover well (Langlet 1929, Henson 1952, Robins & Susut 1974, Schmid *et al.* 1991). In any case, severe injuries have caused significant growth losses (Blyth 1953). The level of growth losses and mortality also depends on the role of *Tomicus* shoot bark beetles in the future decline of the stand. This role is uncertain in the Levi case. Therefore, the Levi red belt has to be re-surveyed in coming years to see the real effects of the red belt contributing factors to Levi forests.

References

Bella, I.E. & Navratil, S. 1987. Growth losses from winter drying (red belt damage) in lodgepole pine stands on the east slopes of the Rockies in Alberta. Canadian Journal of Forest Research 17: 1289–1292.

Blyth, A.W. 1953. Reduction of growth in conifers caused by red belt in the subalpine region of Alberta. Division of Forest Research, Forestry Branch, Department of Resources and Development. Silvicultural leaflet 79. 3 p.
Evenstad, O. 1881. Et Særsyn af Tørke paa Furruen. Den Norske Forstförenings Aarbog 1: 127–128.
Finnish Meteorological Institute, 1991. Meteorological statistics of the Sodankylä observatory.
Hartley, C. 1912. Notes on winterkilling of forest trees. Nebraska University Forest Club Annual 4: 29–50.
Hansen, M. 1921. Innberetning om Ringerike skogforvaltning. Innberetning om Det norske skogvesen etc. for kalenderåret 1920, avgitt av Skogdirektøren. p. 77–80.
Henson, W.R. 1952. Chinook winds and red belt injury to lodgepole pine in the Rocky mountain parks area of Canada. Forestry Chronicle 28: 62–64.
Hørbye, J. 1882. Om frostskader paa barskoven. Den Norske Forstföreningens Aarbog 2: 99–105.
Jørstad, I. 1949. Melding om sykdommer på skogtrærne in 1942–1947. Skogdirektørens årsmelding 1943–1947. 9 p.
— & Roll-Hansen, F. 1943. Melding om sykdommer på skogtrær i årene 1936–1941. Skogdirektørens årsmelding 1941. p. 11–25.
Jalkanen, R. 1992. Får Levi i Kittilä en horisontal slalombacke? Skogskadebältena i västra Lappland undersöks. Skogsaktuellt 1992(1): 24–27.
Klein, W. 1990. A survey of winter damage in the forests of Montana, 1989. USDA Forest Service, Northern Region. Timber, Cooperative Forestry and Pest Management. Report 90–6. 11 p.
Langlet, O. 1929. Några egendomliga frosthärjningar å tallskog jämte ett försök att klarlägga deras orsak. Zusammenfassung: Einige eigentümliche Schädigungen an Kiefernwald nebst einem Versuch, ihre Entstehung zu erklären. Svenska Skogsvårdsföreningens Tidskrift 27: 423–461.
MacHattie, L.B. 1963. Winter injury of lodgepole pine foliage. Forest Research Branch Contributions 536. 4 p.
Melrose, G.P. 1919. Red-belt injury in British Columbia. Canadian Forestry Journal 14: 164.
Robins, J.K. & Susut, J.P. 1974. Red belt in Alberta. Information Report NOR-X-99. Northern Forest Research Centre, Edmonton, Alberta. 7 p.
Schøyen, W.M. 1909. Om frostskade paa furuskog. Tidsskrift for Skogbruk 17: 25–27.
Schmid, J.M., Mata, S.A. & Lynch, A.M. 1991. Red belt in lodgepole pine in the Front range of Colorado. Research Note RM-503. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 2 p.
Skurdal, O. 1908. Frostskade paa furuen i Tolgen. Tidsskrift for Skogbruk 16: 375–377.
Venn, K. 1962. Frostbelter, en sjelden frostskade i Krødsherad. Norsk Skogbruk 18: 591–594.

The effect of nitrogen fertilization on damage to and growth of Scots pine on a mineral soil site in Sodankylä, northern Finland

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Abstract

The effects of nitrogen fertilization on the growth and state of health of a 65-year old stand of Scots pine (*Pinus sylvestris* L.) established on a dryish mineral soil site were examined in Sodankylä, northern Finland. The amount of nitrogen in the fertilizer treatments applied in 1982–1984 varied within the range 0–1000 kg/ha. Stand growth, damage and the nitrogen concentration of the pine needles were monitored for a period of 5–7 years from the date of fertilization.

The first visible cases of damage to needles resulted from a nitrogen fertilizer level of 150 kg/ha. Top diebacks (drying up of tops of trees) were observed at 200 kg/ha. Both damage to needles and top diebacks became more frequent and more pronounced as the amount of applied fertilizer increased from the above two levels. Only seldom did trees whose tops had been damaged by frost recover from their injuries. Some of the pines (6.2 % of the entire material) died as a result of the damage incurred by them either already during the summer when the fertilizer treatment (350–1000 kg/ha) was applied or within the ensuing 5-year monitoring period.

The nitrogen concentration of the current year's crop of needles rose to a noticeably high level already by the autumn of the year of fertilization. While the nitrogen concentration in the needles of unfertilized trees was c. 11–12 mg/g of dry matter, the highest concentrations (in excess of 40 mg/g of dry matter) were recorded in the case of the highest nitrogen fertilizer treatments. The autumnal nitrogen concentration of the needles correlated well with post-winter damage observed in the pines.

The best height increments were recorded for nitrogen fertilizer treatments of less than 100 kg/ha. High nitrogen levels resulted in marked retardation in height increment. The highest basal area increments (3–4 m^2/ha/5 a) were recorded for nitrogen levels of 150–350 kg/ha. The growth of control trees amounted to 1.8 m^2/ha/5 a. It was only when 750 and 1000 kg of nitrogen per hectare were applied that the basal area increment fell short of that of non-fertilized trees. A nitrogen level of 250 kg/ha raised volume increment to 7 m^3/ha/a as compared to the control value of 3 m^3/ha/a. Annual increments in excess of 5 cubic metres were attained with nitrogen levels of 50, 100–200 and 350 kg/ha. Nitrogen levels of 750 and 1000 kg/ha resulted in volume growth below that of the control trees. The annual volume increment percentage rose from 4 % (control trees) to 8 % (trees treated with 200 kg of nitrogen per hectare).

Introduction

The forestry use of nitrogen fertilizers on the mineral soils of northern Finland began some thirty years ago. The area treated each year has varied between a hundred and a few thousand hectares (Uusitalo

1989). During the past decade and the beginning of the 1990's, however, nitrogen fertilization as a forest improvement measure has almost ceased. The contributing factor has been the more restricted use of forest improvement funds and finally their total withdrawal.

The effective nutrient primarily added on mineral soil sites has been nitrogen. In the early 1980's the recommended level was 150 kg N/ha (Ohjekirje metsän lannoituksesta 1979). At the end of the decade the amount had been reduced to 125 kilos (Ohjekirje metsän lannoituksesta 1982). The reduction in the amount recommended is partly the result of observations that trees with dried up tops are more common in forests that have been fertilized with nitrogen (Lipas *et al.* 1982, Rajamäki *et al.* 1986).

The National Board of Forestry (NBF) in particular had a need to step up the fertilization of mineral soils sites in the early 1980's. It had approximately 500 000 hectares of young thinning stands which, according to NBF's directives, were suitable fertilization targets. A need arose to find out what the role of nitrogen fertilization was in the occurrence of trees with dried up tops. The Finnish Forest Research Institute and NBF initiated a joint nitrogen fertilization study composed of eight individual experiments in different geographical locations between Paltamo and Ivalo (Jalkanen 1984). Results of these experiments have previously been reported on the part of Paltamo (Jalkanen 1990).

Material and methods

The present nitrogen fertilization experiment was located in a forest stand at Siurunmaa, Sodankylä (67°25'N, 26°59'E). The average temperature sum for the study area (at 220 m above sea level) is 760 d.d. (threshold value +5 °C). At the time when the experiment was established in 1982, the naturally arisen stand on the site had reached the stage of first thinning and the age of 65 years. The growing stock was characterized by the following parameters: mean d.b.h. 11 cm, mean height weighted by basal area 9.5 m, volume 77.1 m^3/ha, basal area 13.2 m^2/ha, stem number 1270 stems/ha, all of Scots pine. The site is a dryish mineral soil site classified as being of the *Empetrum-Myrtillus* (EMT) type.

The core of the experiment consisted of what may be referred to as the "nitrogen level experiment" in which 12 different nitrogen levels from 0 (non-fertilized) to 1000 kg/ha were applied as follows:

Sample plot no.	Nitrogen kg/ha	Sample plot no.	Nitrogen kg/ha	Sample plot no.	Nitrogen kg/ha
1	0	5	100	9	350
2	25	6	150	10	500
3	50	7	200	11	750
4	75	8	250	12	1 000

The nitrogen concentration of the fertilizer used was 27.5 % and the nitrogen was in the form of calciumammoniumnitrate. Each treatment consisted of a circular sample plot with a radius of 6 m. The sample plots were surrounded by a belt 3 m in width treated in the same way as the actual sample plot. The distance between the belts of adjacent sample plots (i.e. the width of the non-fertilized area) was at least 4 metres. All trees on the sample plots were sample trees (at least 10 per sample plot). The sample trees were numbered systematically on each sample plot. The total number of sample trees was 517. Prior to being spread, the amount of fertilizer was divided into four parts and each of these was then spread manually within a particular sample plot quarter in order to ensure an even distribution.

The series of 12 nitrogen levels was repeated during three consecutive years. This resulted in a total of 36 sample plots (Fig. 1). The actual fertilization dates were 23 June 1982 (replication 1), 3 June 1983 (replication 2) and 7 June 1984 (replication 3).

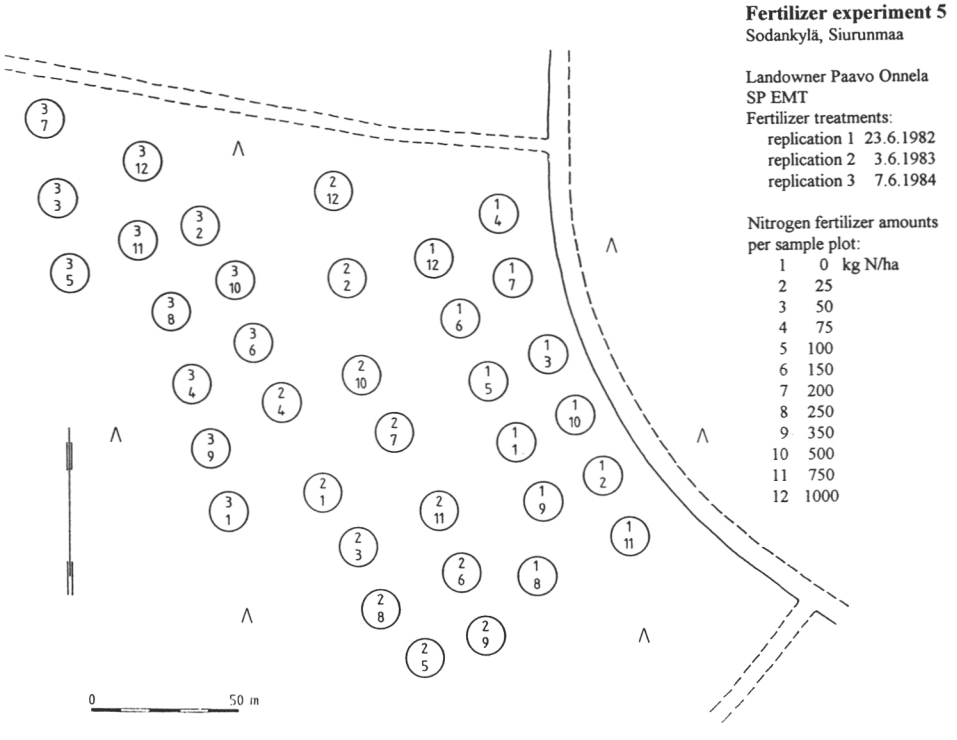

Figure 1. Experimental layout for the Siurunmaa nitrogen level experiment in Sodankylä.

The sample trees were measured each autumn and monitored early summer for a period of 5–7 years following fertilization. Radial growth of the growing stock was calculated on the basis of two d.b.h. measurements taken at right angles to one another and carried out per tree annually. Height increment was recorded as the difference between initial height and height at the end of the 5-year period. If a sample tree happened to die before the end of the measurement period of 5 years, the development of the growing stock parameters was calculated as follows: 1) the growth accumulated by the tree by the time it died represented the entire 5-year period's growth and 2) dead trees were considered to be part of mortality and thus a loss caused by fertilization.

The sample trees were also examined for the presence of biotic agents of damage. The state of health of the foliage was ascertained using the following classification:

Class	Explanation
0	Healthy: normal, green foliage
1	Slight damage: some yellow or brown needles in the top leader, tips of branches green
2	Severe damage: obvious browning of needles, tips of branches brown, secondary branches still green. Browning concentrated in top part of crown.
3	Very severe damage: whole tree brown
4	Tree dead (death caused by fertilization) already by the end of summer of fertilization

Classes 3 and 4 were combined to form class 3 (Dead) because these trees were estimated to die as a result of the damage incurred.

Crown condition was determined as follows:

Class	Explanation
0	Healthy: top leader normal, no growth disturbance
1	Top leader alive but signs of growth disturbance
2	Top leader dead, new leader from lateral branch of same age (case of quick recovery)
3	As in 2 but no new leader to be observed
4	Top leader and 1–2 leaders in the current year's branch whorl dead
5	Top dieback affects more than two uppermost branch whorls
6	Tree dead

Trees in classes 3–6 were considered to be so severely damaged that they were considered to be afflicted by top dieback. These trees had difficulties in producing a new leader.

Three pines on each sample plot (i.e. sample trees 1, n/3 + 1 and 2n/3 + 1) were accessed for needle samples for a nutrient analysis (n = number of sample trees on sample plot) in August–September of the years of fertilization and during 4–6 years thereafter. The samples were taken from the 3rd and 4th branch whorl or from the uppermost living branches. Only the current year's crop of needles was analyzed (Halonen *et al.* 1983). Samples were collected from all three replications. The condition of the needles in the autumn was considered to provide an explanation for the coming spring's damage to trees.

Results

Growth

Height increment

Small and medium doses of nitrogen (25–250 kg/ha) did not induce statistically significant increases in height increment in the fertilized pines as compared to non-fertilized trees. Nevertheless, the height increment resulting from fertilizer amounts below 100 kg was the best (nearly 1.0 m in 5 years as compared to the mean height increment of 0.6–0.9 m in 5 years (Fig. 2a). Excessive nitrogen doses (500–1000 kg/ha), on the other hand, caused a significant reduction in height increment with the mean height increment for 5 years remaining below 0.5 metres. The biggest dose almost caused height increment to cease. Growth retarding effects were observed to begin already at the level of 350 kg.

Basal area increment

Fertilization had a clearly positive effect on the development of the basal area of the growing stock. While the mean basal area increment of the unfertilized sample plot was 1.8 m^2 during the 5-year period, only the two biggest nitrogen fertilizer treatments resulted in basal area increment below that of the control plot. The best basal area increment (> 4 m^2, i.e. double that of the control plot) was recorded for the fertilizer treatment of 200 kg/ha (Fig. 2b). Basal area increments of over 3 m^2 were achieved with nitrogen levels of 150–350 kg/ha.

Volume increment

Fertilization clearly increased the volume growth of the growing stock at nitrogen levels 200–350 kg/ha. Volume growth was also enhanced by small nitrogen doses (50, 100 and 150 kg N/ha). Volume growth at the nitrogen fertilization level of 500 kg equalled that of the non-

fertilized sample plot. The two highest nitrogen levels resulted in volume growth that fell short of the control plot's value (Table 1).

The mean annual volume increment of the non-fertilized growing stock was 3.1 m^3/ha. The highest value of 7.0 m^3 was achieved with 250 kg N/ha while values in excess of 5 m^3 were recorded for nitrogen levels of 100–350 kg/ha (Table 1). Annual volume increment was a mere 1.5–1.9 m^3/ha when the nitrogen applied amounted to 750 and 1000 kg/ha; in the case of the highest nitrogen application, volume increment was, in fact, negative when mortality was taken into account. Mortality at nitrogen levels of 200–1000 kg/ha varied within the range of 1–40 % of the final growing stock at the end of the monitoring period.

The increment percentage varied between less than 3 % (for high nitrogen levels) and the control value of 3.9 % and the other extreme of 7.9 % (for a nitrogen level of 200 kg/ha). When expressed in terms of increment percentage, fertilization had a considerable increment-promoting effect even at the lowest nitrogen level (e.g. 25 kg N/ha gave 5.1 %; Table 1).

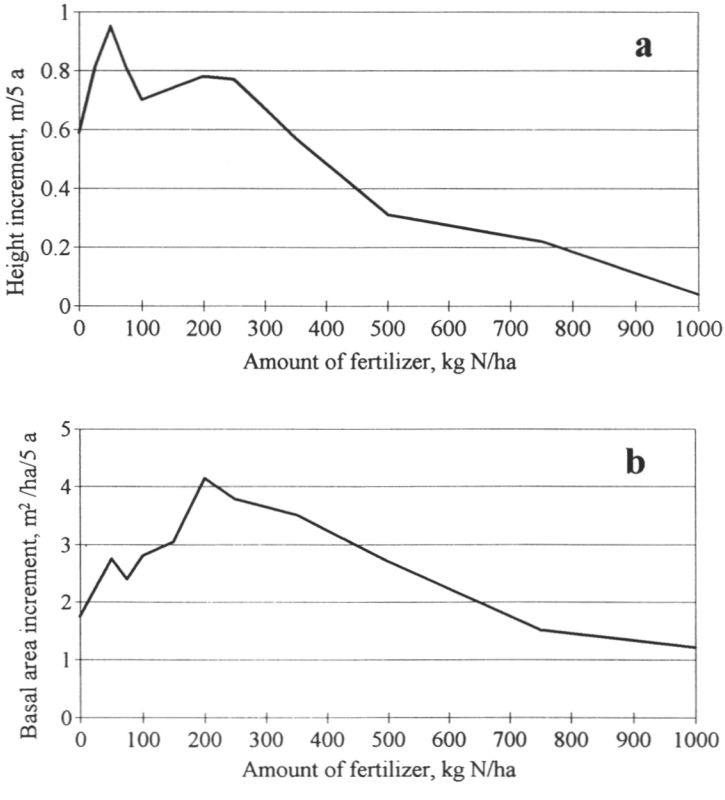

Figure 2a–b. Height (a) and basal area (b) increment of Scots pine during the next five growing periods following fertilizer treatment of varying intensity at Siurunmaa, Sodankylä.

Table 1. The effect of nitrogen fertilization on the volume, volume increment (m^3/ha), volume increment percentage and tree mortality at Siurunmaa, Sodankylä.

Nitrogen level kg/ha	Volume initially m^3/ha	Volume 5 a later incl. mortality m^3/ha	Mortality within 5 a %	Volume increment within 5 a m^3/ha	Volume increment within 1 a m^3/ha	Increment %
0	79.5	95.0	0	15.5	3.1	3.9
25	68.3	85.8	1.0	17.5	3.5	5.1
50	90.1	115.8	0	25.4	5.1	5.6
75	69.2	87.6	0	18.3	3.7	5.3
100	82.3	107.3	0	25.0	5.0	6.1
150	78.5	103.9	0	25.4	5.1	6.4
200	83.8	116.4	1.8	32.6	6.5	7.9
250	97.9	132.7	1.1	34.9	7.0	7.1
350	85.6	114.6	0.6	29.1	5.8	6.8
500	62.9	83.3	7.6	20.3	4.1	6.5
750	51.2	58.7	12.3	7.5	1.5	2.9
1 000	75.8	85.4	39.8	9.6	1.9	2.5

Damage

During treatment summer

The first symptoms of the fertilizer treatment applied in June were observed in the ground vegetation later in the summer. High fertilizer levels caused the vegetation cover, especially bilberry (*Vaccinium myrtillus* L.), to turn brown within a few weeks. Medium levels of nitrogen caused bilberry to turn a darker green and increase in vigour. Lower levels of nitrogen also caused the vegetation to develop a stronger colour in comparison to the non-fertilized area.

Medium levels of nitrogen induced the growing stock to also exhibit signs of increased vigour during the treatment summer; bigger and darker needles were produced by the pines. High nitrogen levels were observed to cause growth disturbances in the leaders produced during the treatment summer. A total of six pines died during the treatment summer; three of these died during the summer of 1982 (replication 1), one in the summer of 1983 (replication 2) and two in the summer of 1984 (replication 3). All these deaths took place on plots treated with 1000 kg N/ha.

During next summer following treatment

Needles on pines treated with nitrogen fertilizer began to turn brown in April about 10 months after the treatment. The browning of needles tended to concentrate on the most recent, treatment summer's needle crop and especially in the upper parts of the crowns (i.e. leaders and tips of branches). In the case of slight damage to the needles of the upper branches, needles produced prior to the treatment summer

remained green. While severe browning of entire trees manifested itself already by the end of April, it was observed that shoots that had lost all their needles might themselves still be alive.

Slight browning of needles began to occur in a few trees already at the level of 150 kg N/ha. Yet there were significant differences between the years in this respect – the worst case of browning of needles during the summer following the fertilizer treatment occurred in replications 2 and 3 (i.e. in the spring of 1984 and 1985). The degree of damage increased with an increase in the amount of fertilizer applied; the increase in the amount of needle damage was accompanied by an increase in its severity (Fig. 3). All replications of treatment 12 (1000 kg N/ha) included trees that were entirely brown and assessed to be dying. The numbers of trees that had died because of the fertilizer treatment within five years of the fertilizer treatment were as follows; seven trees in replication 1 (treatment 12), ten trees in replication 2 (treatments 10, 11, 12), and fifteen trees in replication 3 (treatments 9, 10, 11, 12). This gives a total of 32 trees which is 6.2 % of all sample trees.

Following second growing season

Needle browning was normally concentrated in the spring following the fertilization treatment. However, the severest needle loss affecting pines fertilized in June of 1982 occurred in the spring of 1984 (i.e. a year later than normal).

When the needles that had turned brown in the spring began to be shed and the second post-fertilization growing season was drawing to its close, one could be more certain of whether the top of a particular tree was alive or not. From the point of view of tree growth, loss of the top was observed to be more critical than needle damage. Trees with dried up tops occurred at all fertilization levels to some extent, even on the control plots; this would indicate the concurrent presence of natural abiotic top-damaging agents.

Top dieback cases actually caused by fertilization began to appear at the fertilization level of 200 kg N/ha. At the level of 300 kg N/ha pines afflicted by top dieback amounted to more than 20 % of the stems; the 50 % level was achieved when the nitrogen application level was 500 kg/ha. The highest proportions of trees afflicted by top dieback occurred at 750–1000 kg N/ha levels. At these fertilization levels nearly 20 % of the pines were able to retain a live top. Generally speaking, the relative proportion of trees afflicted by top dieback was slightly higher during the second year following the fertilization treatment as compared to the first post-fertilization year. This situation remained unchanged during later inventories (Fig. 4). However, the proportion of top diebacks in replication 1 (fertilization in summer of 1982) was only 3.5 % in 1983 but a year later it rose to 20.7 % for the same trees. Differences of this magnitude were not observed in the other replications (Fig. 5).

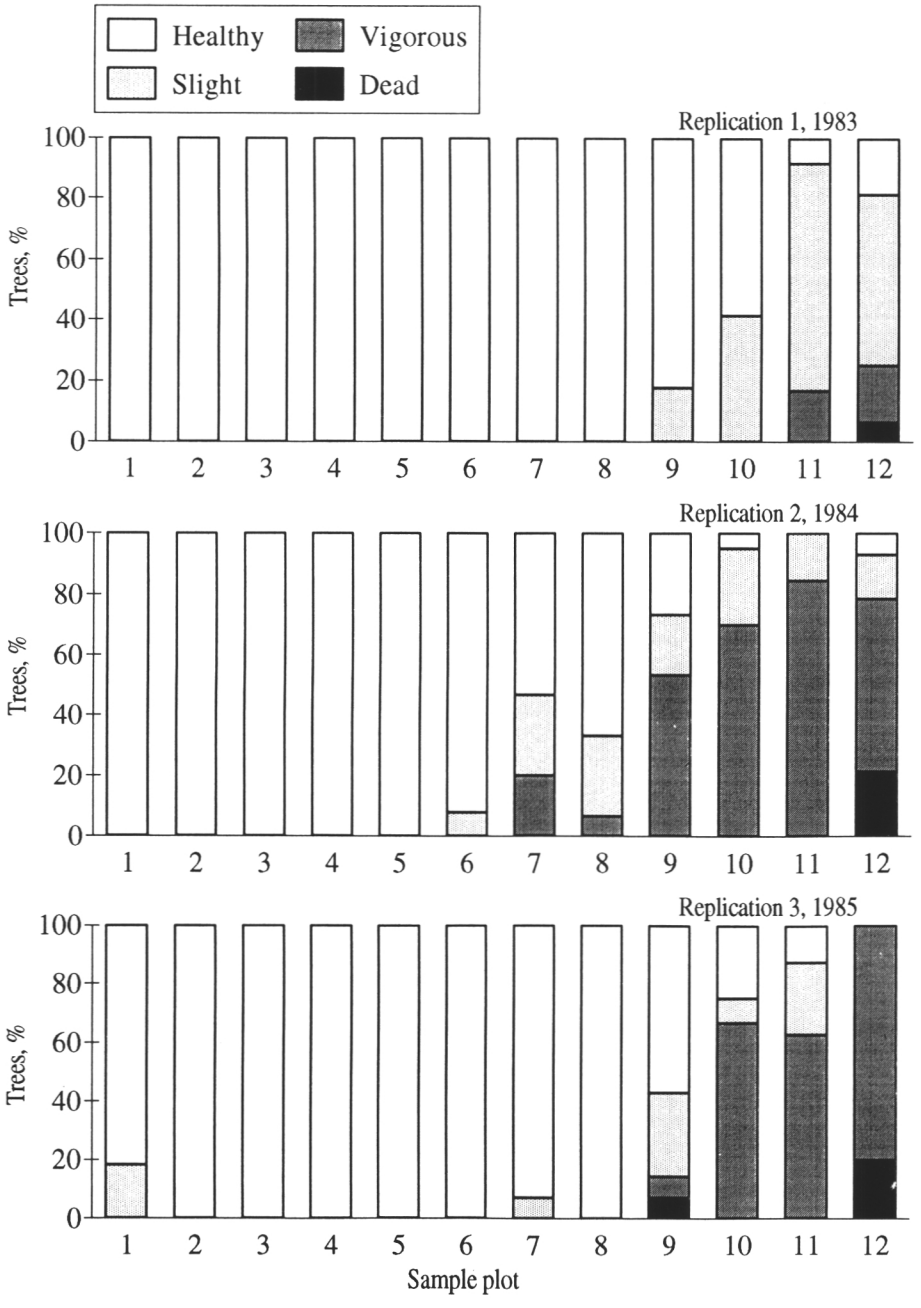

Figure 3. The degree of browning of pine needles during the spring following nitrogen treatment of varying intensities at Siurunmaa, Sodankylä (replication 1 in the spring of 1983, replication 2/spring 1984 and replication 3/spring 1985). For connection between sample plot number and nitrogen level see Fig. 1.

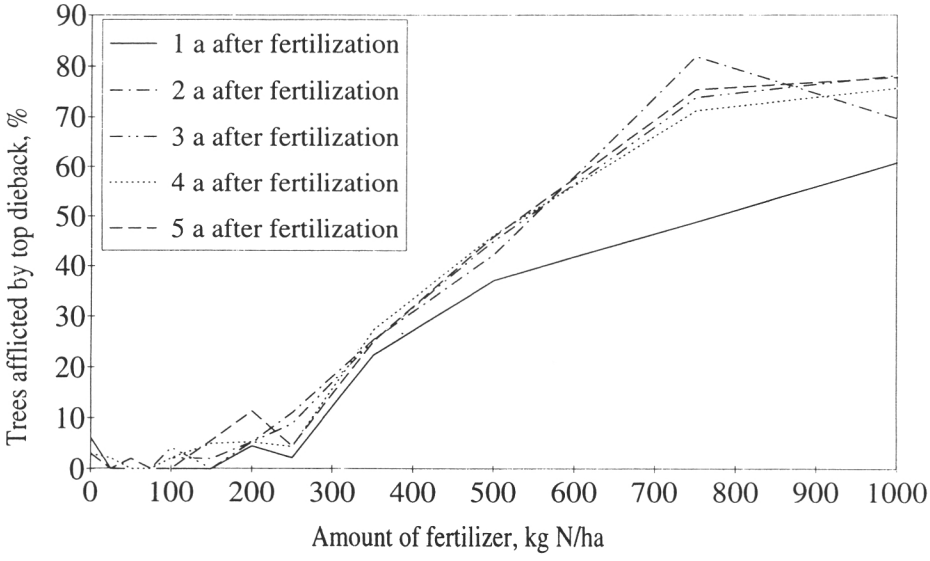

Figure 4. The relative proportion of trees afflicted by top dieback at various nitrogen levels 1–5 years after the fertilization treatment at Siurunmaa, Sodankylä. The means for all three fertilization years.

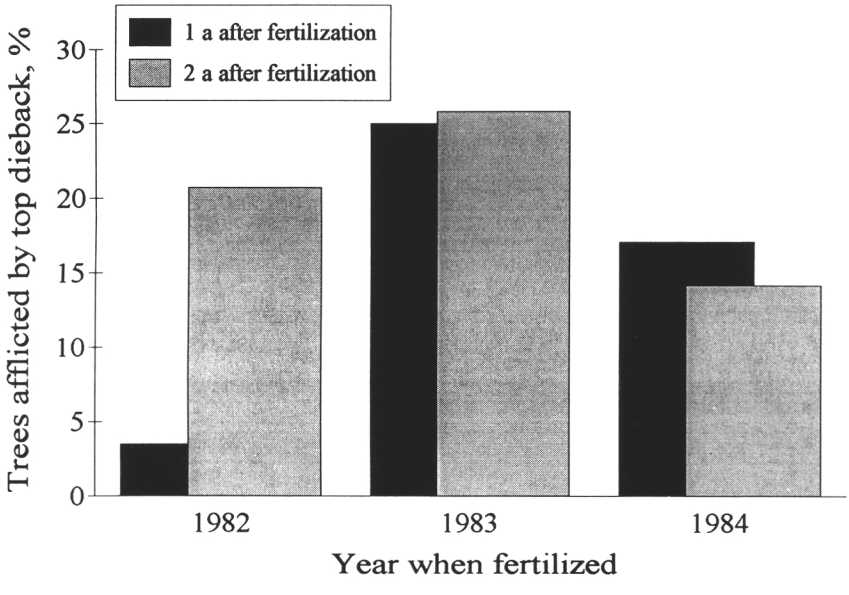

Figure 5. The relative proportion of trees afflicted by top dieback according to the fertilization year 1–2 years after the fertilization treatment at Siurunmaa, Sodankylä. The means for all 12 nitrogen levels.

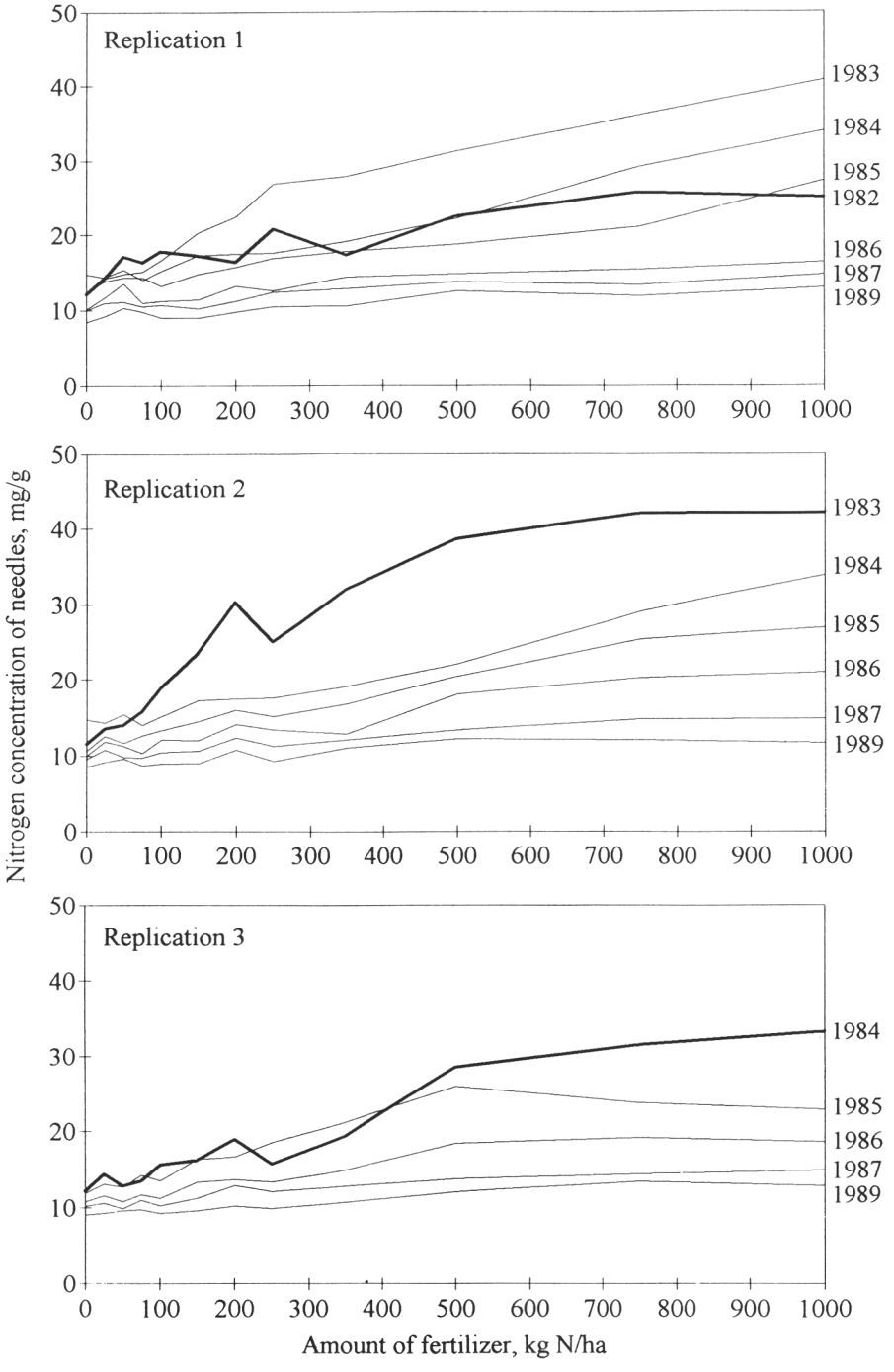

Figure 6. The correlation between the nitrogen concentration in the current year's needles (mg/g of dry matter) and the amount of fertilizer applied in June, the year of application (replication) and the time passed since the application of fertilizer at Siurunmaa, Sodankylä.

Nitrogen concentration of needles and damage to trees

Nitrogen concentrations

The nitrogen concentrations of needles generally rose in accordance with increasingly higher fertilization levels. However, the highest fertilization levels brought about only minor changes. The highest nitrogen concentrations recorded in the current year's needles in the autumn were over 42 mg/g of dry matter expressed as sample plot means. In the case of individual trees, the corresponding figure was 49 mg/g while that of non-fertilized trees was 12 mg/g of dry matter at the end of the first growing season. Generally, the highest values were recorded in the autumn of the year of fertilization (i.e. in 1983 and 1984). In the case of replication 1 the highest concentrations were recorded towards the end of the second summer (September 1983) after fertilization (June 1982). The nitrogen concentrations in the current year's needles fell rapidly from one year to the next to the extent that the nitrogen concentrations of needles produced during the fourth (replication 3) and fifth (replications 1 and 3) year after fertilization no longer differed from the normal level (Fig. 6); this was especially the case with trees that had received high doses of nitrogen.

Nitrogen concentrations and damage to trees

No significant browning of needles was observed in the trees in the spring in the case of needles whose nitrogen concentration was less than 21 mg/g of dry matter. The resultant damage was severe when concentrations exceeded 29 mg (Fig. 7). However, some trees even with as high as 30 mg/g nitrogen concentration did not show any needle damage.

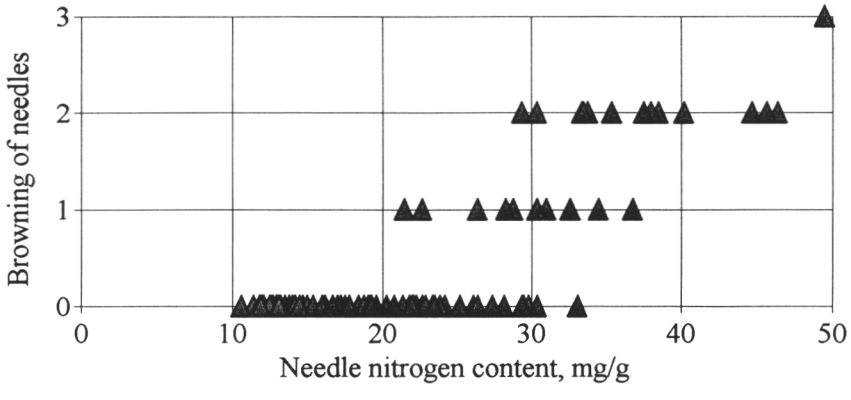

Figure 7. The correlation between spring-time needle browning and the nitrogen concentration (mg/g of dry matter) of damaged needles per year of fertilization as recorded during the previous autumn at Siurunmaa, Sodankylä (each triangle represents single tree).

Discussion

In accordance with what was assumed, it was observed that the degree of damage caused by fertilization to the Scots pines was increasingly higher the higher the amount of fertilizer. The browning of needles that tended to concentrate in the spring of the year following the application of nitrogen fertilizer began to manifest itself at the nitrogen level of 150 kg/ha whereas the subsequently observed top dieback first occurred at 200 kg N/ha. In 1982, the time when this fertilization experiment was commenced, the recommended dose for forestry application of nitrogen fertilizer in southern Lapland was 150 kg/ha. Although Siurunmaa with its 760 d.d. temperature sum is outside the scope of forest improvement funding (min. temperature sum 800 d.d.), and therefore north of the zone of 'acceptable' fertilization, this experiment and the more northerly Ivalo experiment (Jalkanen 1984) were established to provide comparison values for the six experiments located in the more southerly climatic zone. Keeping this in mind, the results obtained are quite interesting. Needle damage at Siurunmaa is of equivalent or even lesser degree than that observed in the corresponding thinning stage stand fertilized in the warmer (260 d.d. higher) conditions near the shoreline of Lake Oulujärvi in Paltamo (Jalkanen 1990). Nor was the occurrence of top dieback any more frequent in Sodankylä – in both locations the 50 % proportion of top dieback was achieved at the nitrogen level of 500 kg/ha while visible damage began to occur at 150 kg N/ha.

The first year's fertilization treatments at Siurunmaa differed from the next two years with regard to the resultant damage. The very evident explanation to this is in the clearly later date of fertilization at the end of June in 1982. This in turn means that the nitrogen concentrations in the needles produced in the summer of 1982 did not rise nowhere near as high as they did in the same trees' new needles the next year and in the needles of trees in the other replications during the summer when fertilization was applied. Thus it would appear that the previous autumn's nitrogen concentration of the needles has influence on the amount of resultant damage. This was observed to apply in Paltamo as well (Jalkanen 1990). In fact, the similarity in the severity of damage is understandable since the maximum nitrogen concentrations recorded at the two locations were of the same order – over 40 mg/g of dry matter. Moreover, considering that the growing stocks in both cases were of the local provenance and of natural origin, and that the climate in Siurunmaa is considerably harsher than that in Paltamo, the Siurunmaa growing stock would appear to be more resistant than its counterpart in Paltamo. The fact that the Siurunmaa plots were treated about three weeks later than Paltamo does not dim this point of view – in relation to the growing season both sets of plots were treated at the time of bud flush. The only exception to this was Siurunmaa replication 1; consequently, its nitrogen concentrations had not changed by the end of the growing season.

Seeing as the nitrogen concentrations in the needles were clearly connected to both needle browning and top dieback, the nitrogen concentration in the autumn following fertilizer treatment can be used as a means of predicting the risk of damage to the growing stock the following spring.

It is obvious that if one is to avoid damage to the growing stock, 150 kg N/ha is not a suitable fertilization prescription. The appropriate amount is less than this. When defining a safe amount, consideration must be given to the fact that the results given here are based on an experiment in which the fertilizer was spread absolutely evenly. In practice the very problem is how to achieve even spread when fertilizing stands. Consequently, the recommended levels can easily be exceeded twofold (Rajamäki *et al.* 1986). In other words, it is not impossible for the prescribed level of 100 kilos to actually be 200–300 kg/ha in places – and thus the risk of damage would be highly possible. This being the case, nitrogen fertilization is no longer rational at the latitude of Sodankylä if the present climate exists.

However, if one is prepared to accept minor damage to the growing stock – browning of needles and perhaps even a few cases of top dieback – fertilization does result in a clear gain in increment. This is the case not only in relative growth but absolute as well; e.g. volume increment of 5.1 m^3/ha/a (mean for the next 5 years following fertilization) produced by 200 kg N/ha as compared to the control figure of 3.1 m^3/ha/a. Trees afflicted by top dieback increase in radius and they can be removed in the next thinning operation. This is necessary as it appears that such trees are far less able to produce a new top than trees that simply lose their top due to it is breaking off for some reason.

The present study dealt only with the resistance of a young thinning stand. Many other studies and experiences on this subject indicate that mature stands are tougher than young stands. Top dieback in the case of trees that have reached the final cut stage is of no relevance from the standpoint of logging yields because tops become part of the logging residue. In a young stand, however, top dieback means the end of height increment and thereby loss of potentially merchantable timber.

The various forms of damage connected to elevated nitrogen concentrations in the foliage appear in the spring (mainly in April) and fall in the category of frost-drought or freeze-drying. In the spring, as a tree begins to prepare for the summer, its internal metabolism picks up speed. The changes referred to are at their most sensitive form in connection with high nitrogen fertilization levels. A tree needs water when its shoots become active in the spring. This is especially the case in the top of the crown. If the roots are still frozen and the sun already heats up the surroundings on a windless sunny day in Siurunmaa, a demand for water arises and this demand cannot be met via the soil.

The crown of the tree, and especially needles with high nitrogen concentrations (and thus less able to retain their moisture content), finds itself in a state of water deficiency (Tranquillini 1986). If this situation is followed by a cold night (–10 °C – –20 °C), those parts of the plant that are in a state of water deficiency lose the little water they still have and then freeze. This damage always takes the form of browning of needles soon after it has occurred and always prior to the beginning of the growing season. As compared to *Gremmeniella abietina* (Lagerb.) Morelet shoot damage, successful infection becomes visible once the growing season has begun (Jalkanen 1985).

It is interesting to compare the nitrogen amounts applied and the local nitrogen deposition values. Needle browning required a minimum of 150 kg N/ha. When divided among seven years (the recommended interval between fertilization treatments) this results in an annual dose of 21 kg N/ha. The region's annual nitrogen deposition has been 2–3 kg N/ha in the middle of the 1980's (e.g. Kuukausikatsaus Suomen ilmastoon 1987). Even though these figures cannot be directly compared (e.g. because of the lack of the gaseous component in fertilization) nitrogen deposition is far too low for it to cause any discernable damage at a latitude such as that of Sodankylä or other area of low deposition. On the contrary, the fact that the low nitrogen levels induced improved height increment is an indication of a slight nitrogen deficiency and this is probably fairly general for the soils in Lapland. Since the worst forms of damage caused by fertilization are produced immediately following fertilization, the nitrogen concentration in question is considerably higher than 21 kg/ha. The above observations also lead to the conclusion that climate has a central role to play in post-fertilization damage.

References

Halonen, O., Tulkki, H. & Derome, J. 1983. Nutrient analysis method. Metsäntutkimuslaitoksen tiedonantoja 121. 28 p.

Jalkanen, R. 1984. Pohjoissuomalainen lannoituskoesarja maaperäekologisen tutkimuksen käyttöön. Jyväskylän yliopiston biologian laitoksen tiedonantoja 40: 58–59.

— 1985. Die-backs of Scots pine due to unfavourable climate in Lapland. Aquilo Series Botanica 23: 75–79.

— 1990. Nitrogen fertilization as a cause of dieback of Scots pine at Paltamo, northern Finland. Aquilo Series Botanica 29: 25–31.

Kuukausikatsaus Suomen ilmastoon. Ilmatieteen laitos. Helsinki. 1987.

Lipas, E., Levula, T. & Välikangas, P. 1982. Eräitä metsänlannoitustuloksia Lapista. Metsäntutkimuslaitoksen tiedonantoja 114. 12 p.

Ohjekirje metsän lannoituksesta. 1979. No Mh. 327. Metsähallitus. 10 p.

— 1982. No Mh. 305. Metsähallitus. 10 p.

Rajamäki, J., Jalkanen, R. & Karjula, M. 1986. Vuosina 1980–1984 lannoitettujen kasvatusmänniköiden latvavauriot kivennäismaalla Pohjois-Suomessa. Metsähallitus, kehittämisjaosto, tutkimusselostus 148. 26 p.

Tranquillini, W. 1986. Frost-drought and its ecological significance. In: Lange, O.L., Nobel, P.S., Osmond, C.B. & Ziegler, H. (eds.). Physiological plant ecology. II. Water relations and carbon assimilation. Encyclopedia of Plant Physiology, new series, vol. 12B. Springer-Verlag, Berlin - Heidelberg - New York. p. 379–400.
Uusitalo, M. (ed.). 1989. Metsätilastollinen vuosikirja 1988. Statistical yearbook 1988. Folia Forestalia 730. 243 p.

Defoliation of pines caused by injury to roots resulting from low temperatures

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Abstract

Factors affecting the exceptional premature yellowing of the oldest needles of Scots pine (*Pinus sylvestris* L.) in the peak of the growing season of 1987 were studied experimentally in the field by cold-stressing pine roots in winter, by defoliating pines, and by cutting pine roots in northern Finland. The needle loss was preceded by a snowless but cold (even –40 °C) December 1986. Symptoms linked with the phenomenon were heavy needle loss of the peak of the growing season, reduced shoot growth and mini-needles of 1987, dead surface roots and even dead pines. The needle loss was hypothesized to have been caused 1) by cold via root injuries or 2) by air pollutants.

Roots of 2–5-meter tall pines were subjected to cold with or without natural snow cover in the winters of 1987/1988 to 1989/1990. The soil surface was protected from snowfall by poly greenhouses. Minimum temperature of the snowless area was colder than –20 °C at a depth of 5 cm in the dry, fine-textured sandy soil. Oldest needles of the pines with cold-treated roots turned prematurely yellow in early July following the treatment. Some trees died.

In four artificial defoliation treatments, all but 0, 1, 2, or 3–4 green needle year classes of about 2-meter tall pines were removed in spring 1989. The resulting reductions in shoot growth and needle length were not apparent until the second growing season after defoliation.

Zero, 25, 50, 75 or 100 percent of the surface roots of 2–4-meter tall pines were cut at a one-meter-distance from the stem in the beginning of growing season of 1990. In July 1990, the oldest needles of the trees with greatest root reduction began to turn yellow, as well, shoots and needles did not reach normal lengths.

It was concluded that root injury and death from severe cold temperatures have been the main causal agent of the needle loss of Scots pine during the peak of the growing season of 1987. Yellowing of the needles was due to translocation of mobile nutrients and water from the oldest needle sets to younger one(s) and meristems. The results are supported by the subsequent recovery of the affected stands.

Introduction

In the mid-summer (July) of 1987, exceptional yellowing of the oldest needles was observed to occur in Scots pines (*Pinus sylvestris* L.) over an area of approx. 1 million hectares in the southern parts of northern Finland; this was especially the case on the drier mineral soils and on bogs (Jalkanen 1988). In some cases, the yellowing and death of needles extended to even the youngest, 1-year old needles. The average

needle loss entailed 2–3 year classes of needles (Jalkanen 1990). There are no previous written reports of corresponding "mistimed" yellowing of the older needle year classes affecting large areas and there are other reasons too that make this so-called "Lapland needle loss" a very unusual phenomenon (Ritari 1990). Along with loss of needles by pines, the environment was observed to have suffered other forms of damage as well (Jalkanen 1988).

In addition to the exceptionally early and abundant needle loss, Scots pines in Finnish Lapland were characterized in the summer of 1987 by clearly reduced height increment (especially of branches), very short current-year needles and damaged root systems. In the central parts of the needle loss area, the damage to trees was so extreme that some pines died during the summer of 1987 without losing their needles. However, trees in the affected area began to recover from their injuries by producing extra long needles during the summer of 1988 and by beginning to compensate for root damage through new roots already during the summer of 1987. The lowest level in height increment was, however, reached during the summer of 1988. Top dieback occurred in the summer of 1988 as a follow-up damage in pine stands within the needle loss area. This suggests that a nutrient-based growth disturbance might be involved.

In the clarification looking into the causes of the needle loss, emphasis was placed on the central role of damage to root systems. While the winter of 1986–87 had been an exceptionally cold one, it was the concurrent thin cover of snow (Ritari 1990) that is believed to have played an important role in launching the phenomenon. Nevertheless, the possible direct impact of pollutants on needles was also taken into account in the investigation. According to one school of thought, it is believed that 1) the needle loss was caused solely by pollutants (especially ozone), 2) the shortness of the 1987 needles was a consequence of the concurrent major needle loss, and 3) the decline of root systems was a result of the trees' efforts to rectify their root/shoot ratio which had been skewed by their loss of needles. This report looks at the above hypotheses by means of studying empirically the effects of damaging roots and removing needles on the condition of trees.

Material and methods

Experimental stands

The study was confined to two localities in northern Finland (Sattanen = S, Hietaperä = H) and one locality in southern Finland (Jämi = J). All the experimental stands were naturally arisen stands of Scots pine, 1.5–4.0 metres in height, and located on dry, sorted sandy heathland. Their ages varied within the range 10–35 years. The stands

in Hietaperä lost their needles during the summer of 1987, while the more northerly stands in Sattanen and the southerly stand in Jämi were not afflicted by needle loss (Fig. 1). The Sattanen and Jämi stands differed significantly from the Hietaperä stands in terms of height increment. The events leading to the needle loss of the summer of 1987 caused marked height growth reduction during the years 1987–88 only within the needle loss area – i.e. the Hietaperä stand (Fig. 2). The analyses of wet deposition carried out in the experimental stands showed that the sulphur and nitrogen load in Jämi (N_{tot} 1138 µg/l; SO_4 3.0 mg/l) was about twice that obtained for Hietaperä (N_{tot} 563 µg/l; SO_4 1.9 mg/l) and Sattanen (N_{tot} 448 µg/l; SO_4 1.8 mg/l). It was hypothesized that trees in more polluted areas show a higher susceptibility to root cold injuries. Dry, sandy heathland soils are typically covered by a layer of *Cladonia* spp. Owing to the large reindeer population in the reindeer husbandry area (inc. Sattanen and Hietaperä), this layer has been browsed away there, but not in the southern parts of Finland (inc. Jämi). It is believed that this has an impact on the ecology of trees.



Figure 1. Location of the experimental areas and the needle loss area of the midsummer of 1987.

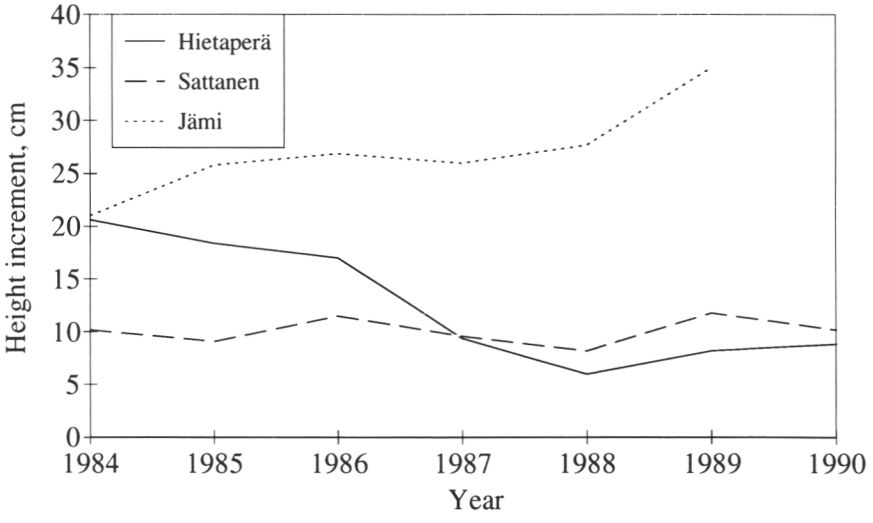

Figure 2. Height increment during 1984–90 of the control trees of the experimental stands.

Root cold stress experiments

Roots were cold stressed by either a) preventing the accumulation of snow onto ground by means of a shelter partly open at its walls but allowing the temperature of the soil to vary according to the temperature of the surrounding air in mid-winter (all winters) or b) irrigating the top of the soil in autumn in order to have massive freezing of the soil occur either through the snow (winter 1987–88, H) or under the shelter without a cover of snow (1988–89, H, S, J and 1989–90 H and S). An additional treatment was executed whereby the top of the soil was protected by a 10 cm layer of straw from September to April (1988–89).

The treatment plots measured 10 m × 10 m. There were 30–50 trees per experimental plot. Depending on the winter in question, there were 1–4 replications. The condition of the trees, and especially of the needles, was monitored during the summers following the treatments. The results cover the first two winters.

Soil and air temperatures and soil freezing and the depth of the snow cover were also monitored during the root cold stress experiments.

Artificial defoliation experiment

Early in the summer of 1989, an experiment consisting of the artificial defoliation of trees was established in the Hietaperä area. This was done by leaving either 0, 1 or 2 full needle year classes on the stems and branches of the trees. The control trees had 3–4 needle year

classes – i.e. the same number that the sample trees had before the defoliation treatment. There were a total of 50 sample plots. Each of the four trees per sample plot represented one of the treatments. The height increments of the sample trees for the years 1986–90 were measured in the autumn of 1990. These measurements were accompanied by the counting of the number of needle year classes and the measurement of needle length.

Experimental root cutting

In May of 1990, a root cutting experiment was established in the Hietaperä area. The surface roots of pines were cut with a spade to a depth of 20 cm within a radius of 1 metre from the stems of the trees. The intensity of the cutting varied between 0, 25, 50, 75 and 100 per cent. Each of the 20 sample plots carried five sample trees, one per treatment. The cutting of the roots was always performed in the same manner; e.g. the 25 per cent intensity of cutting was always oriented between north and east. Variation in tree size within individual sample plots was kept to a minimum. The average minimum spacing of sample trees within individual plots was no less than 2.5 metres. The condition of the trees was monitored monthly during the summer of 1990. Measurements connected to the number of needle year classes and length of needles were carried out in the autumn of 1990. The height increment for the years 1986–90 were measured from four branches of the 5th branch whorl.

In the case of all the above experiments, the needle year classes were determined from the main stem or bole and from four branches applying an accuracy of 0.25 needle year classes. Depending on the experiment in question, the branches belonged to the 5th–10th branch whorl.

Results

Root cold stress

Falls in air temperature were accompanied by obvious falls in the soil temperature of snowless plots. A corresponding reaction in soil temperature was recorded during rises in air temperature. During the coldest spells, the soil temperature at a depth of 5 cm fell below –20 °C. The mid-winter temperature under a cover of snow remained at a steady –5 °C – –7 °C and it was hardly affected by variations in air temperature. Under the cover of straw, the temperature fell at its lowest just below freezing point.

Both lack of snow and a cover of ice with snow mixed in caused the premature yellowing of old needles early in July of 1988. The needle loss meant the loss of about a quarter of the needles that had over-

wintered. About 10 per cent of the pines on stressed sample plots died (Table 1).

Height increment on the sample plots continued to decline more than on the control sample plots which were influenced only by the stress factors that had led to the needle loss of the summer of 1987 (Table 2). Some of the sample trees lost their top as a result of dieback. Cold stressing of roots, on the other hand, did not give rise to needles less than average in length.

Even during the mild winter of 1988–89, induced massive soil freezing and the lack of snow led to a slight yellowing of the needles during the summer and to needle loss in the autumn when compared to control plots. This difference was at its most evident in the Hietaperä area. The protection provided by the cover of straw prevented needle loss in all three areas. While the straw treatment did not prevent late summer yellowing of needles in the Jämi area, it did have a significant effect in both of the northern areas where hardly any needles were shed naturally. This was especially the case in the Hietaperä area (Table 3). The emergence of new needles was normal in this area as well.

Table 1. Effect of root cold stressing on the number of needle year classes in Scots pine and the vigour of the trees in the Hietaperä experimental area, Rovaniemi, northern Finland. The trees were stressed during the winter of 1987–88 and monitored over the summer and autumn of 1988.

	Number of needle year classes				
	Total Winter 87–88	Yellowed July 88		Total Autumn 88	Mortality
Treatment	nof.	nof.	%	nof.	%
Snowless	2.9	0.5	17.2	3.4	7.8
Field of ice	2.9	0.7	24.1	3.2	11.7
Control	2.8	0.1	3.6	3.7	0.0

Table 2. Effect of root cold stressing on the relative height increment of Scots pine in the Hietaperä experimental area, Rovaniemi, northern Finland. The height increment for 1986 has been the value 100 within each treatment. The trees were stressed during the winter of 1987–88.

	Annual height increment, %		
	1986	1987	1988
Snowless	100	54.2	23.1
Field of ice	100	63.6	28.4
Control	100	62.1	35.0

Table 3. Effect of root cold stressing on the number of needle year classes in Scots pine in mid-summer and late summer in the Hietaperä, Sattanen and Jämi experimental areas. The trees were stressed during the winter of 1988–89 and monitored over the summer and autumn of 1989.

	Locality (Number of needle year classes)					
	Hietaperä (4.8–4.9)		Sattanen (4.8–4.9)		Jämi (3.3)	
	Needle loss 1989					
	July	Total	July	Total	July	Total
Control	0.0	0.3	0.1	0.5	0.0	0.6
Snowless	0.1	0.6	0.1	0.7	0.1	0.8
Snowless + ice	0.2	0.6	0.2	0.8	0.1	0.6
Layer of straw	0.0	0.1	0.0	0.3	0.0	0.6

Artificial defoliation

Artificial defoliation carried out in the beginning of the growing season had no effect on the same year's (1989) height increment. Although the pines had had all their over-wintered needles (i.e. pre-1989 needles) removed, their height increment during 1989 recovered in the same manner as that of control trees from the low caused by the factors leading to the needle loss of the summer of 1987. The effect of artificial defoliation on the height increment of the second year (i.e. 1990), on the other hand, was of significance in that all artificial defoliation treatments caused the height increment for 1990 to be less than that recorded in 1989. The maximum reduction in height increment (nearly 3 cm when compared to control measurements) was recorded for those trees that had had all their over-wintered needles removed (Fig. 3). However, the reduction in growth that the trees underwent between the summer of 1986 (the summer preceding the needle loss summer of 1987) and the summer of 1988 was far greater – it fell from a level of approx. 13.5 cm down to 5.5 cm.

Artificial defoliation did not lead to premature yellowing of the needles in July of neither 1989 or 1990. While natural late summer yellowing did occur to some extent in control trees in the autumn of 1990, none was to be observed in trees with one or no needle year classes left on them early in the summer of 1989. Thus, these trees had 3 or 2 needle year classes in the autumn of 1990. Their needle length was reduced only during the summer of 1990 in the more drastic treatments.

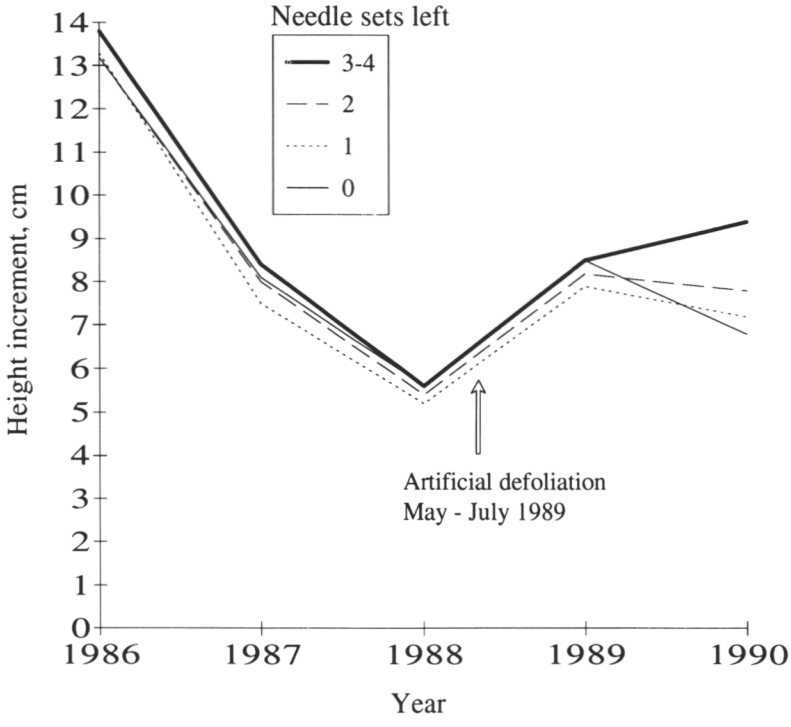

Figure 3. Effect of artificial defoliation on the height increment of Scots pine in the Hietaperä experimental area.

Root cutting

The cutting of roots that was implemented in May of 1990 led to the premature yellowing of the oldest needle year classes two months later. Together with the late summer yellowing of needles, the needle loss amounted to over a quarter of the number of needle year classes in the treatment involving the cutting of all surface roots. In the treatments involving the cutting of 50–75 per cent of the surface roots, the needle loss amounted to over a fifth (Fig 4.). The absolute loss was approx. 1.5 needle year classes for trees that had had all their surface roots cut; the corresponding figure for the control pines was only 0.7.

There was a marked reduction in the length increment of the branches from 1986 to 1988 in the same way that stem height increment behaved with artificially defoliated trees. Nevertheless, the branch growth for the summer of 1990 was less than a year earlier in all treatments – it was at its worst in trees that had been damaged the most and at its best in control trees.

The cutting of roots had a marked effect on the length of needles for that year. The control trees were the only ones with the 1990 needle year class being longer than those of the preceding year. The more severe the cutting of surface roots, the shorter the 1990 needle year class needles were. The needle length of the 1990 needle year class for control trees was more than 0.5 cm longer that of the 1989 needle year class. In the case of trees subjected to cutting of surface roots, this ratio was reversed. With root cutting percentages of 25, 50, 75 and 100, the corresponding needle lengths were 3, 4, 6 and 8 mm less (Fig. 5). During the last five years, the needles had been shorter than in 1987 when they were on the average 6.2 mm shorter than in 1989. Thus, their length corresponds to the level achieved by cutting 75 per cent of the surface roots.

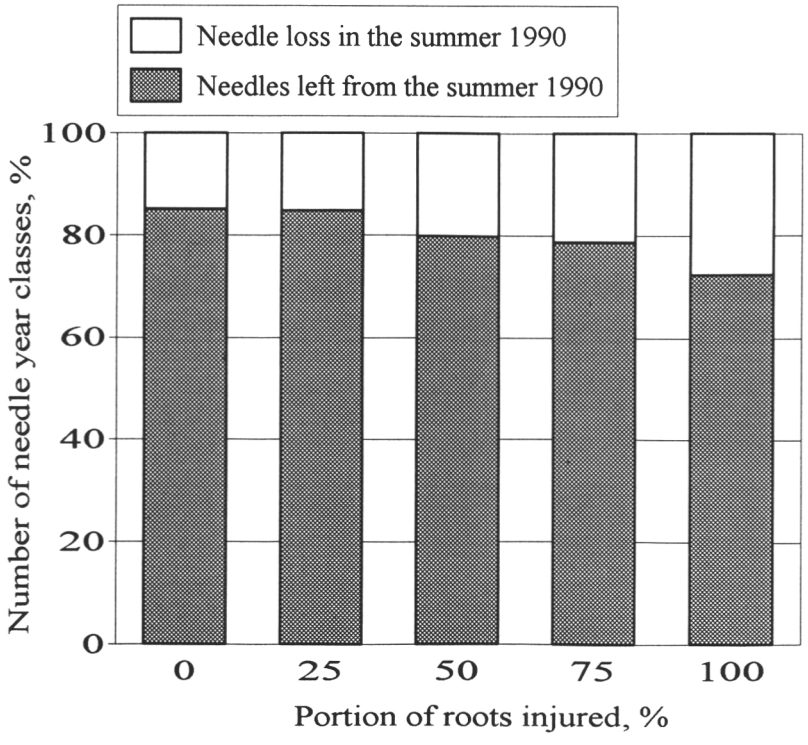

Figure 4. Effect of root cutting on the relative needle loss of Scots pine during the summer of 1990 in relation to the total number of needle year classes on trees in the Hietaperä experimental area. The root cutting was done during late May in the summer of 1990.

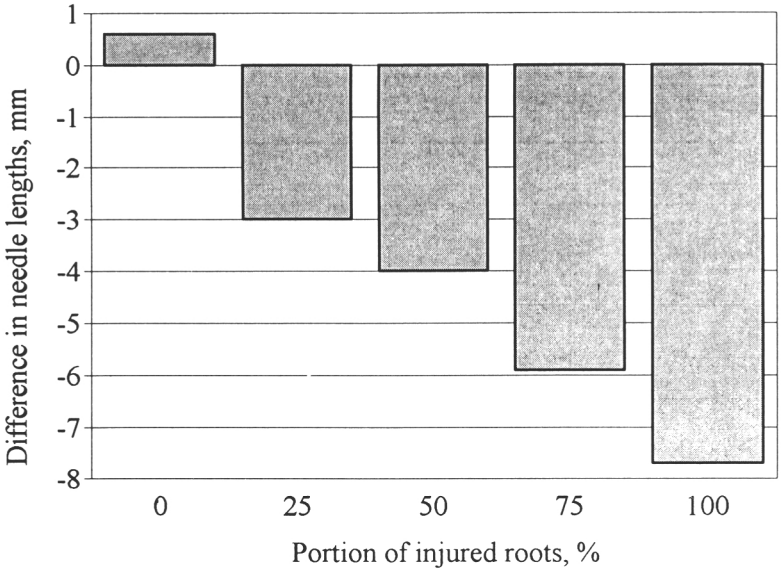

Figure 5. Effect of root cutting on the length of Scots pine needles in 1990 in relation to needle length of the preceding year's needles in the Hietaperä experimental area.

Discussion

Of the symptoms connected to the mid-summer needle loss following the winter of 1986–87, we were able to experimentally repeat the following:

1. Mid-summer needle loss by subjecting roots of trees to cold or by cutting surface roots of trees
2. Reduction in growth especially by cutting surface roots of trees and also by subjecting roots of trees to cold
3. Short needles by cutting surface roots of trees
4. Dying of young trees by subjecting roots of trees to cold and
5. Top dieback by subjecting roots of trees to cold.

Since the artificial defoliation of trees did not reduce tree growth nor shorten needle length during the summer of the needle loss, but did so during the second growing season, the 1987 needle loss itself cannot be considered to have led to a reduction in growth and the production of short needles during the same summer. Although the root system of the trees was examined quite superficially, it would seem that the defoliation of the trees has no effect on root vigour. On the other hand, because the hindering of root functions either by cold stressing or cutting them induced the more important needle loss symptoms, there is a clear correlation between root damage and needle loss. Given that

pine root damage begins already at –10 °C (Lindström & Nyström 1987), it is apparent that the exceptionally cold winter of 1986–87 made it possible for the roots of trees to be damaged and, to an extent, to be killed. The experiments on snowless sandy heathland soil plots resulted in temperatures as low as –20 °C in the root layer of the soil. The soil temperature during the winter of 1986–87 must have dropped even further because the air temperature in December–January of 1986–87 went as far down as –40 °C over areas free of snow (Ritari 1990).

The experimentally induced cold stressing of roots did not promote needle loss in Jämi when compared to Sattanen and Hietaperä even though the pollution load in Jämi was clearly greater than in the other two. This being so, pollutants cannot have had a decisive role as inducers of root damage and needle loss.

Since the reaction speed of height increment to changes in the environment is generally slower than that of radial growth, the marked reduction in height increment must be a consequence of some sudden and significant environmental factor. As the trees that had undergone the needle loss of the summer of 1987 were quick in recovering from it, this recovery combined with the above observation provides grounds for barring, in certain parts of Finnish Lapland, pollutants (and especially ozone) as potential causes of the needle loss.

There is reason to believe that the mid-summer needle loss was a result of nutrient deficiency caused by cold damage to roots. Problems in providing sufficient amounts of nutrients and water caused trees to begin translocating mobile nutrients from the older needles to safeguard the functioning of the newer needles and meristematic tissues. This in turn led to the premature yellowing of the older needles. Had trees not been able to do this, vast areas of forests in northern Finland would have been lost. This interpretation is supported by the observation that there were trees that died already during the summer of the needle loss and others with weakened root systems within the needle loss area that died because of lack of water following the extremely dry July of 1988.

The results would seem to indicate that protecting tree roots from sub-zero temperatures (e.g. by a layer of straw) promotes the trees' capacity to retain needles over the winter. In other words, it is possible to reduce defoliation by protecting the roots from frost. While this observation concerning the beneficial effect of covering tree roots has no practical significance for the practice of forestry, the fact that a layer of straw increased the crop of needles in the Sattanen and Hietaperä experiments where the soil lacks its former cover of lichen, the results obtained in this study may have far-reaching effects. Indeed, further studies should be conducted to find out what effect overgrazing of lichen areas and the disappearance of the protective lichen layer has on soil temperature, the condition of roots, and the defoliation of trees in northern Finland.

References

Jalkanen, R. 1988. Karisevatko viimeisetkin neulaset Pohjois-Suomen puista? [Will there be any needles left on Scots pine in northern Finland?] (In Finnish). Teollisuuden Metsäviesti 1988(1): 8–11.

— 1990. Root cold stress causing a premature yellowing of oldest Scots pine needles. In: Merrill, W. & Ostry, M.E. (eds.). Recent research on foliage diseases, conference proceedings. USDA Forest Service, Genetical Technical Report WO–56. p. 34–37.

Lindström, A. & Nyström, C. 1987. Seasonal variation in root hardiness of container-grown Scots pine, Norway spruce, and lodgepole pine seedlings. Canadian Journal of Forest Research 17: 787–793.

Ritari, A. 1990. Temperature, snow and soil frost conditions in northern Finland during winter 1986–87 viewed against a longer recording period. Nord 1990(2): 44–52.

Monitoring of abiotic forest diseases in Norway

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Abstract

An overview of forest damage situation in Norway is made by combining results of forest health surveys and diagnosis and mapping of forest diseases. From 1990 to 1991 there has been a significant increase in yellowing of Norway spruce (*Picea abies* (L.) H. Karst.) in southeastern Norway. Chemical analyses of needles have revealed deficiencies, or suboptimal levels, of magnesium, potassium and nitrogen. Drought is the most plausible inciting cause. The discolouration was mainly located in those parts of Norway having the greatest amounts of long range air pollution, and the predisposing effect of those are possible, but undetermined. High and fluctuating temperatures during the winter and spring of 1990–1991 resulted in different kinds of climatic damage, e.g. red belts, winter and late frosts, and desiccation.

Introduction

Monitoring of forest damage in Norway has recently been increased because of the concern that chronic air pollution may weaken forests and increase damage from abiotic and biotic forest diseases (Manion 1981). Annual forest health surveys are made using the appearance of tree crowns while work on diagnosis and mapping of forest diseases, as reported by local foresters, is being intensified. The combined results of these surveys give an excellent overview of forest damage in Norway.

Material and methods

Each year since 1988 forest health has been evaluated in 772 local county plots containing about 47 000 trees. Assessments are made by rating crown density and colour during the autumn (Solberg 1991). Because of the large number of trees that are being evaluated we are able to obtain the overall picture of damage for the counties or geographic regions of Norway.

Diagnosis and mapping of damage is based upon reports from local forest officers, followed by on site inspection and sample collection. Priority is given to defoliation and discolouration symptoms. The main studies being done on the abiotic diseases are chemical analysis of needles and anatomical analysis of wood (microscopy). Recognition and distribution of the symptoms within a stand and on individual trees

are important diagnostic criteria as are other general observations such as water conditions in soil and tree growth rate. Experts from several disciplins are taking part in the diagnoses.

Results

The surveys of the local county monitoring plots have shown only small changes in crown density from 1988 to 1991. From 1990 to 1991 there has been a significant increase in yellowing of Norway spruce (*Picea abies* (L.) H. Karst.) in the southernmost part of southeastern Norway.

Several cases of yellowing of needles, especially on Norway spruce, have been reported and investigated in the last two years, particularly in southeastern Norway (Solberg *et al.* 1992). The symptoms often resemble nutrient deficiency. The most frequent symptom has been yellowing of one year old and older needles, especially towards the needle tips. Another prevalent symptom that is a light chlorosis, distributed evenly over all needles and branches. Sometimes both symptom types are found together. Some trees with symptoms have top die-back, or shortening of shoots and needles.

Chemical analyses of needles have revealed deficiencies, or sub-optimal levels, of magnesium, potassium and nitrogen, either alone or in all combinations.

Drought or frost rings are often found in affected trees and this has led to the hypothesis that such symptoms may be incited by drought or frost. In 1991 drought may have been the main factor inciting needle yellowing, as the weather was dry both early (April, May) and late (July, August) in the season.

Whitney & Timmer (1983) reported drought as a cause of yellowing of spruce needles. Drought has also been found to reduce nutrient concentrations in needles (Christiansen & Nilsen 1990). Hüttl (1991) explains magnesium deficiency in spruce in Germany as partly caused by drought.

At present it is not possible to determine the extent to which long range air pollutants are predisposing trees to the yellowing symptoms observed in our studies. However, all the reports of yellow discolouration of spruce in 1991 and also most cases from the local county plots indicated that yellowing increase (from 1990 to 1991) in those parts of Norway having the greatest amounts of acid deposition and the highest ozone concentrations. These major annual changes from green to yellow crown colour in the last three years may indicate that the forests in this region are more prone to damage than elsewhere in Norway.

Another type of yellowing symptom observed on Norway spruce is pale, yellow brown current-year needles. Although the needles do not have an intense yellow colour, the crowns of affected trees appear yellowish. This symptom was especially prevalent in Oppland county in the inland of southeastern Norway during the summer of 1991. The cause of the symptom is not known, but harsh weather (e.g. frosts, drought and wind) during the spring of 1991 may have damaged the buds or new needles.

Numerous attacks by *Chrysomyxa abietis* (Wallr.) Unger were observed in 1991. Various kinds of yellow flecking symptoms are also observed on Norway spruce and from an undetermined cause on Norway spruce and Scots pine (*Pinus sylvestris* L.). These symptoms are thought to be of little importance compared to the needle yellowing observed in southern Norway.

Beside the yellowing symptoms different kinds of frost damage occurred frequently in 1991. Abnormally high and fluctuating temperatures during the winter and spring of 1990–1991 resulted in several reports of damage throughout Norway.

After the winter of 1990–1991 red belt damage occurred in some localities in the inland of southeastern Norway, where the size of individual red belt affected areas ranged up to about 1 km^2. Damage occurred at specific elevations, with damage being confined to 'belts' on hillsides, or to larger, less defined areas in flat terrain. Mainly Scots pine and Norway spruce were affected, and both species exhibited the same symptoms. In the red belts, damage was most severe on exposed trees and exposed parts of trees, and occurred in certain cardinal directions indicating that wind must be an important factor in such damage. On the most severely affected trees many buds were killed. Several times throughout the winter mild winds with precipitation came in from the coast, and presumably the wind and fluctuating temperatures caused the problem. Red belt damage also occurred in at least one area last winter (1991–1992).

Winter frosts alone or in combination with desiccation also caused some damage throughout Norway during the winter of 1990–1991. One frost which occurred about 20 April was followed by mild weather for two weeks. In some places along the coast this led to winter burn on conifers and some deciduous trees which had began to grow suffered late frost damage on the new shoots.

It has also been observed that frost and drought during summer retard needle maturation which results in winter injuries.

Air pollution may predispose trees to different types of frost damage, but because such damage is widespread and invariably associated with abnormal weather conditions indicates that frost alone is responsible for the damage.

References

Christiansen, E. & Nilsen, P. 1990. Effekt av tørke og nitrogen. In: Stuanes, A. (ed.). Skog og miljø – vekst og vitalitet. Seminar 13. Desember 1990. Aktuelt fra NISK nr. 5. p. 18–29.

Hüttl, R.F. 1991. Die Blatanalyse als Monitoring-Instrument im Waldökosystem. IUFRO and ICP-Forest workshop on monitoring, Prachatice, CSFR. p. 139–147.

Manion, P.D. 1981. Tree disease concepts. Englewood Cliffs, New York. 399 p.

Solberg, S. 1991. Fylkesvise lokale overvåkingsflater. Vitalitetsregistrering 1991. Local county monitoring plots. Vitality survey 1991. Rapporter av skogforskning 1991(12). 21 p.

— , Solheim, H., Venn, K. & Aamlid, D. 1992. Skogskader i Norge 1991. Forest damages in Norway 1991. Rapporter av skogforskning 1992(21). 31 p.

Whitney, R.D. & Timmer, V.R. 1983. Chlorosis in planted white spruce at Limestone Lake, Ontario. Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario, Information Report 0-X-346. 16 p.

Symptoms of sulphur dioxide injury to some boreal plants

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Abstract

High concentration of sulphur dioxide is known to be harmful to plants. Damage to several boreal plants caused by sulphur dioxide is here reported from the border areas between Norway and Russia. The symptoms are described in text and colourplates. High levels of pollutants in plant tissue are documented through chemical analysis.

Introduction

Atmospheric sulphur dioxide (SO_2) originates from both natural and man made sources with volcanic activity being the main natural source. Heavy industry, and specifically metal smelters, are common man made sources of SO_2 emissions in the boreal areas of NW Russia. SO_2 is a gas under normal conditions. The major effects of SO_2 on forest plants are well known (Linzon 1978, Tamm & Aronsson 1972) with severity of damage depending on SO_2 concentration. At relative low concentrations SO_2 may not be harmful to plants or it may even have a positive effect where soil sulphur is a limiting factor. Severity of damage depends on the plant species and age (Linzon 1978), but SO_2 is normally harmful to plants, especially near the source of emissions. A common effect in many plant species is destruction and reduction of chlorophyll (Singh 1989). Major damage is mostly related to episodes of very high SO_2 concentrations and results in necrosis of plant tissues. However, destruction of chlorophyll can occur without subsequent necrosis (Lauenroth & Dodd 1981), e.g., under chronic exposure to low concentrations of SO_2. Sublethal amounts of SO_2 may stunt plant growth (Lendzian & Unsworth 1983). Factors such as light, pH and age of tissue determine the effect on the plant.

This paper describes symptoms of SO_2 injury on some common boreal plants. When observing such symptoms it is important to bear in mind the mediating influence of various factors such as those mentioned above.

In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 93–102.

Materials

Plant samples were collected from 1986 to 1991 in northern Norway and northern Russia (69°–70°N, 30°E) along the Norwegian-Russian border, close to the nickel smelter at Nikel on the Kola Peninsula in Russia (Fig. 1). Very high concentrations of atmospheric SO_2, up to 3000 µg/m³, occur in the area (Sivertsen *et al.* 1992). Only plant species showing symptoms that could be related to air pollution were selected. The samples were photographed in the field and in the laboratory. Samples have been analysed for mineral nutrients and some heavy metals according to Ogner *et al.* (1991).

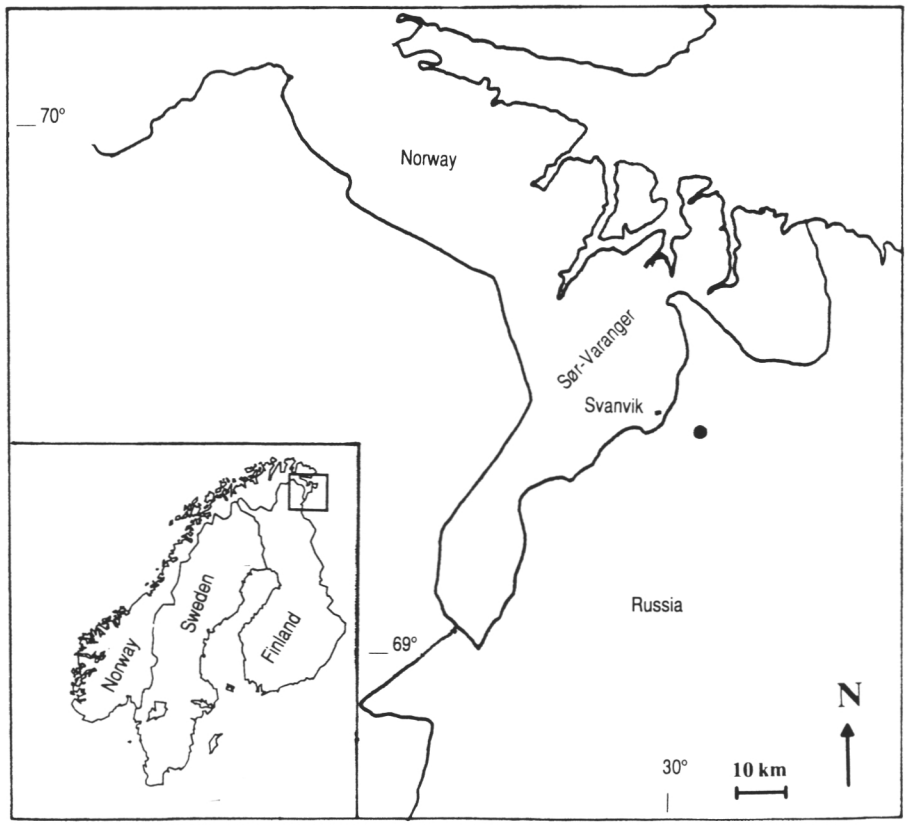

Figure 1. Areas where plants were sampled.

Results

Symptoms of SO_2 injury were found on *Pinus sylvestris* L., *Betula pubescens* Ehrh., *B. nana* L., *Salix caprea* L., *Populus tremula* L., *Sorbus aucuparia* L., *Vaccinium uliginosum* L. and *Vaccinium myrtillus* L. Foliage symptoms common to all of these species are slight chlorosis and brownish necrosis, except in *P. tremula* where the necrotic tissue is more blackish. The description of symptoms on the individual species follow.

Pinus sylvestris: Symptomatic tissue is brown and occurs on the extremities of needles or the needle tips. Usually there is a narrow yellowish transition zone between the necrotic tissue and the living green tissue. The amount of symptomatic tissue varies, e.g, in 1987 at a location close to Svanvik (10 km northwest of the emission source) symptoms were found only on the 1986 needles with about 30 % of each needle being damaged (Fig. 2). These needles later dropped prematurely. At a location about 18 km northwest of the emission source only the distal 5–10 % tip of the 1986 needles were symptomatic. These needles remained on the tree. Chemical analysis of injured needles showed elevated concentrations of nickel, copper and sulphur at both localities, especially at the locality close to Svanvik (Table 1).

Betula pubescens: Symptomatic tissue is brown to reddish brown and occurs on the periphery of the leaf and also between the veins in more or less distinct flecks (Fig. 3). The amount of symptomatic tissue varies from locality to locality, within the tree crown, and between older and younger leaves. Middle-aged leaves are most severely affected. Chemical analysis showed elevated concentrations of nickel, copper and sulphur (Table 1).

Betula nana: Symptomatic tissue is brown to reddish brown and mostly occurs on the leaf periphery (Fig. 4), but sometimes symptoms occur over the entire leaf. When present, symptoms are found on almost all the leaves in a population of *B. nana*. Chemical analysis of non-symptomatic leaves showed high concentrations of nickel, copper and sulphur (Table 1).

Salix caprea: Symptomatic tissue is brown to reddish brown and occurs only between the veins of the leaf (Fig. 5). Only small spots of symptoms occur along the edge and the distal end of the leaf. However, because only a few observations of this species have been made these symptoms may not be typical for the species, and other symptoms may also occur. Chemical analysis revealed elevated concentrations of nickel, copper and sulphur (Table 1).



Figure 2. *Pinus sylvestris*, Sør-Varanger, Norway, 1987.



Figure 3. *Betula pubescens*, Sør-Varanger, Norway, 1991.



Figure 4. *Betula nana*, Sør-Varanger, Norway, 1991.



Figure 5. *Salix caprea*, Nikel, Russia, 1990.



Figure 6. *Sorbus aucuparia*, Nikel, Russia, 1990.



Figure 7. *Populus tremula*, Nikel, Russia, 1990.



Figure 8. *Vaccinium uliginosum* and *Vaccinium myrtillus*, Nikel, Russia, 1991.

Sorbus aucuparia: Symptomatic tissue is dark brown and has only been observed between the veins of the leaf, mostly along the main vein (Fig. 6). Necrosis along the edges of leaves is rare. Small patches of yellowish chlorotic tissue is located between the veins over the entire leaf. However, since only a few observations have been on this species, other symptoms may occur. The chemical analyses showed that concentrations of nickel, copper and sulphur were high (Table 1).

Populus tremula: Symptomatic tissue is dark brown to black and mostly found along the edges of leaves (Fig. 7) which contrasts to the situation on *S. caprea* and *S. aucuparia.* A relatively large transitional zone of yellowish chlorotic tissue occurs between the blackish necrotic tissue and the living green tissue. Concentrations of nickel, copper and sulphur were high in affected leaves (Table 1).

Vaccinium uliginosum and *Vaccinium myrtillus:* Symptomatic tissue of *V. uliginosum* is brown, with necrosis occurring over the entire leaf surface except for a band of green tissue along the main vein and the lower portion of some lateral veins (Fig. 8). *V. uliginosum* and *V. myrtillus* often grow together, but few symptoms seldom occur on *V. myrtillus.* On *V. myrtillus* only the tip or outermost part of the leaf is affected. Chemical analysis of leaves of non-symptomatic *V. myrtillus* from the air pollution affected areas had elevated concentrations of nickel, copper and sulphur (Table 1).

Damage was also found on *Empetrum hermaphroditum* Hagerup (Böcher), but the symptoms are more characteristic of severe frost.

Table 1. Concentrations of sulphur, nickel and copper in needles and leaves of plants from polluted areas and non-polluted areas[1].

Species, and type of foliage	Sulphur, mmol/kg (d.w.)		Nickel, µmol/kg (d.w.)		Copper, µmol/kg (d.w.)	
	Polluted	Non-polluted	Polluted	Non-polluted	Polluted	Non-polluted
Pinus sylvestris[2]						
current year needles	31	20–25	363	< 100	198	50–60
1 year old needles	33	15–20	565	< 100	287	30–50
2 year old needles	34	15–25	491	< 100	275	25–45
Betula pubescens, leaves[3]	103	35–50	2280	< 20	1019	< 90
Salix caprea, leaves[3]	249	60–70	9154	160–170	6110	110–140
Sorbus aucuparia, leaves[3]	128	25–35	4831	< 30	3405	70–100
Populus tremula, leaves[3]	161	70	5153	80–100	2919	110–120
Betula nana, leaves[4, 5]	ca 70	ca 50	800	< 40	400	< 100
Vaccinium myrtillus, leaves[4, 5]	ca 80	45–60	200	< 20	200	ca 100

1) The non-polluted data area average values from samples of non-polluted locations in Norway.
2) Symptomatic needles from Svanvik, Norway.
3) Symptomatic leaves from Nikel, Russia.
4) Ni and Cu from Aamlid 1992, S from unpublished data from the same areas as Aamlid 1992.
5) Not symptomatic leaves.

Discussion

The sampled material represents only a limited selection of plants with symptoms that most probably can be attributed to SO_2. Emissions of SO_2 are very high in the sample areas where for brief periods concentrations up to 3000 µg SO_2 per m^3 of air have been reported (Sivertsen *et al.* 1991). These concentrations are peak values and are most common during the winter. However, peaks also occur during the growing season. Symptoms are mostly found on plants nearest to the emission source. However, weather factors such as frost and drought can not be ruled out as causing some of the damage as SO_2 symptoms may be similar to those resulting from frost and drought. It is also known that high levels of SO_2 increase the susceptibility of plants to frost damage. However, factors such as nearness of the emission source, topography and exposure in the area where the symptomatic plants were growing indicate that air pollution is the most likely cause. The elevated levels of nickel, copper and sulphur in the tissue of the various plants (Table 1) provide further evidence of air pollution damage in the area.

Necrotic needle tips or parts of leaves were the most common symptoms observed during these studies. Shaded plants had less severe symptoms than exposed plants. Symptoms severity on individual plants could be related to pollution loads within a geographic area with plants growing closest to the emission source being the most damaged. The most obvious example of this was the symptom found on pine needles from 1986.

Based on the symptoms found on some leaves of *B. pubescens*, time of the year when the emission episode occurs seems to be important. This is probably related to the physiological age of the leaves with middle aged leaves seeming to be most sensitive. These observations agree with those of Sekiya *et al.* (1982) who studied SO_2 injury in the *Cucurbitaceae*.

E. hermaphroditum was found very close to the emission sources and so it might be very tolerant to SO_2. This finding agrees with Russian experience in polluted areas where Tsvetkov (pers. comm.) reports also *Arctostaphylos uva-ursi* (L.) Spreng. and *Artemisia vulgaris* L. as being tolerant to SO_2. The symptoms found here on boreal plants agree with SO_2 symptoms on various forest trees in the eastern United States (USDA Forest Service 1987).

Acknowledgement

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Samples in Figs. 5, 6 and 7 were collected by K. Venn, while samples in Figs. 2, 3, 4 and 8 were collected by the author. All the photographs are by author. The chemical analyses were done at the Chemical Laboratory, NISK. The author is grateful to Prof. K. Venn for comments on the manuscript and to Dr. J. Sutherland for correcting the language.

References

Aamlid, D. 1992. The concentration of nickel and copper in some important plants in South-Varanger, Norway. In: Kismul, V., Jerre, J. & Løbersli, E. (eds.). Effects of air pollutants on terrestrial ecosystems in the border area between Russia and Norway. Proceedings from the first symposium, Svanvik, Norway 18.–20. March 1992. Norwegian State Pollution Control Authority, Oslo. p. 202–209.

Lauenroth, W.K. & Dodd, J. 1981. Chlorophyll reduction in western wheatgrass (Agropyron smithii Rydb.) exposed to sulphur dioxide. Water, Air & Soil Pollution 15: 309–315.

Lendzian, K.J. & Unsworth, M.H. 1983. Ecological effects of atmospheric pollutants. In: Lange, O.L., Nobel, P.S., Osmond, C.B. & Ziegler, H. (eds.). Encyclopedia of Plant Physiology, Vol. 12D, Springer Verlag, Berlin. p. 465–502.

Linzon, S.N. 1978. Effects of airborne sulfur pollutants on plants. In: Nriagu, J.O. (ed.). Sulfur in the environment: Part II, Ecological Impacts. Wiley, New York. p. 109–162.

Ogner, G., Opem, M., Remedios, G., Sjøtveit, G. & Sørlie, B. 1991. The chemical analysis program of the Norwegian Forest Research Institute, 1991. Norwegian Forest Research Institute, Ås. 21 p.

Sekiya, J., Wilson, L.G. & Filner, P. 1982. Resistance to injury by sulphur dioxide. Correlation with its reduction to, and emission of, hydrogen sulphide in Cucurbitaceae. Plant Physiology 70: 437–441.

Singh, R. 1989. Foliar response of Polyanthia longifolia to SO_2-pollution. Acta Botanica Indica 17: 140–142.

Sivertsen, B., Hagen, L.O., Hellevik, O. & Henriksen, J.F. 1991. Luftforurensninger i grenseområdene Norge/Sovjetunionen januar 1990 – mars 1991. NILU Oppdragsrapport 96/91. Norsk institutt for luftforskning, Lillestrøm. 128 p.

— , Makarova, T., Hagen, L.O. & Baklanov, A.A. 1992. Air pollution in the border areas of Norway and Russia. Summary report 1990–1991. Presented by the Expert Group on Studies of Local Air Pollution Problems under the Joint Norwegian - Russian Commission on Environmental Co-operation. Institute of Industrial Ecology Problems of the North, INEP Kola Science Centre, Apatiti & Norwegian Institute for Air Research, Lillestrøm. 14 p.

Tamm, C.O. & Aronsson, A. 1972. Plant growth as affected by sulphur compounds in polluted atmosphere. A literature survey. Royal College of Forestry, Department Forest Ecology and Forest Soils, Research note No. 12. Stockholm, Sweden. 53 p.

USDA Forest Service. 1987. Diagnosing injury to eastern forest trees. USDA Forest Service, Pennsylvania, USA. 122 p.

On the dynamics of coniferous stand degradation under industrial impact on the Kola Peninsula

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Abstract

The dynamic series of forest change under the influence of different technogenic factors' combination in the zone of the copper-nickel integrated plant activities are analysed. The main stages of stand degradation are revealed. The time of complete stand collapse, barren ground and technogenic desert formation by different combinations of technogenic factors are determined.

Introduction

The expansion of exploitation of nature and intensive management cause great changes in the natural environment and disturbances in the ecological balance. The destruction of natural complexes and the creation of technogenic deserts has acquired special meaning on the Kola Peninsula. Scientists pay much attention to the problem of the destruction of the natural complex in the region (Doncheva 1978, Karpenko 1981, Kryuchkov 1985, Nikonov & Lukina 1989, Lesnai ekositema ... 1990). In most papers, when discussing the processes of stand destruction, the authors do not analyse the temporal laws and their conditioning by technogenic factors accompanying industrial emissions (recreation, cuttings, fire, etc.). The author of this paper set out to determine the date of forest ecosystem degradation and destruction under the influence of different combinations of impacts.

Material and methods

The author used material from more than 40 sample plots including 16 permanent plots on which estimations of stand condition were carried out 2–3 times during periods of 2–8 years. Most plots (29) were over-mature, sparsely spaced stands of Y–Ya site bonitet and with total phytomass amounting to 80–120 tons/ha. The investigations covered more than 90 000 ha of the territory of the Monchegorsk forest enterprise and the Lapland Biospheric Reserve. A detailed silvicultural-pathological and economic-ecological inventory was carried out of the disturbed areas near a copper-nickel plant (a total area of c. 20 000 ha).

The levels of atmospheric pollution by sulphur dioxide were estimated on 28 sample plots using the method of passive gas absorbents produced on the basis of lead dioxide. The pollution levels were characterized by the so-called "SO_2 activity in the air". The unit of measurement was 1 mg SO_4 accumulated by 1 dm^2 of the absorbent area during day and night. Soil pollution by metals was estimated using the method of snow surveys.

The criterion of stand condition was the average maximum needle age, the visually estimated degree of defoliation, the quantity of top-dieback trees and dead tree stems. At the early stages of regressive successions, the methods of lichen indication were used. The predominant type of tree colonization was estimated according to the 10-mark grading system and the abundance of bearded lichen forms (*Usnea* spp., *Bryopogon* spp.) according to the 5-mark grading system. The damage classes used in forest monitoring and marks of life condition suggested by the author were used as integral indicators of condition (Tsvetkov 1990).

Parallel measurements of the current pollution levels and complex of stand condition indicators made it possible to determine the space and temporal laws of forest ecosystem change.

The prediction of rates of regressive processes and their estimation in retrospect were carried out with the help of specific indices and values obtained during the known time of pollution loads (doses). On the basis of these data, equations were derived for the connections between the conditions of stands of the main forest types and the values of pollution indices (mg SO_4/dm^2 absorbed $\times$ 50 years of plant activity).

These connections can be characterized by the equations of a straight line:

Piceetum empetrosum	$y = 0.53340 + 0.1824x$
Piceetum myrtillosum	$y = 0.53698 + 0.15754x$
Piceetum herbosum	$y = 0.54626 + 0.14640x$
Pinetum vaccinosum	$y = 0.177711 + 0.18489x$

Simultaneously, the rate of regressive processes was estimated on the basis of their space-time connections' analyses. The following principle was applied: "... if two geographic events follow each other in time, they should as space phases have a common boundary." We accepted that the criterion of the ecosystem condition (through the complex of morphological criteria) is the received dose of pollution. As it is known, this dose is directly proportional to the duration of the emission effect and inversely proportional to the distance from the emission source. Thus, pollution loading received by any natural object and its condition changes are adequate to extra load and condition changes registered by change in distance from the emission source.

Results

During the past 13–15 years, the volumes of sulphur dioxide emissions in the investigated region have amounted to 220 000–270 000 tons/a according to official figures. According to calculations using traditional models of emission dispersion in space, about 90 % of the emission volumes are dispersed over a territory which takes the form of an extended ellipse with axes of 120–130 and 25–30 km.

Over the main part of the territory, the emission impact on forest ecosystems is accompanied by other anthropogenic impacts. Some emissions manifest themselves only at the edges of the dispersion zone. Nearer to the emission source, the pollution loading and the diversity of impacts increases and the total technogenic stress intensifies. Around an integrated plant, natural ecosystems are affected by strong aerotechnogenic pollution as well as by forest cuttings, fires, recreation and household pollution.

Several stages are observed in regressive successions of over-mature spruce stands of the *myrtilloso-empetrosum* type. Visually observed changes in condition (registered with the help of maximum needle life and degradation of epiphytic lichens of the genera *Usnea* and *Bryopogon*) are noted as the aerotechnogenic pollution load reaches 120 kg of transit sulphur dioxide per hectare of stand in the presence of metal dust.

Under very heavy pollution, the first signs of changes in the assimilatory system structure are noted during the first few years. After 8–11 years, damage to big trees is noted (top dieback and drying up of individual trees). After 20–25 years, parts of stands die, open woodland is formed with viable young growth and a shrub layer. After 40–45 years, the tree layer dies and the young growth and shrub layer are oppressed. Complete death of the tree-shrub layers takes place after 55–60 years. The destruction of ground vegetation begins and soil erosion develops. After 65–70 years, barren ground of the *empetrosum* type with dead cover is formed on the site. After 75 years, sandy-boulder technogenic desert is formed (Table 1). Soil on such sites is washed away down through to the illuvial layer and it is heavily polluted by metal compounds.

When the pollution load decreases, regressive processes slow down. When the pollution level is adequate to the SO_2 activity 0.33–0.55 mg SO_4/dm^2, the final stage of degradation is barren ground, but not eroded desert. Under moderate pollution, regressive processes are covered by generation successions. Spruce-birch low open forests are formed with continually changing viability.

The course of regressive processes is precipitated when the technogenic load becomes complex: cuttings, fires, household pollution are added to emissions. Under most heavy industrial pollution, barren grounds of *empetrosum* type with dead cover and open shrubs are formed already in 33–35 years, and in 37–40 years, technogenic desert is developed accompanied by a transformed ecotone.

Table 1. The dynamics of stand destruction and formation of technogenic deserts under the influence of different technogenic factors in the zone of active industrial emission influence.

Nature of technogenic influences		Dates of destruction stages according to pollution levels, years					
		Heavy atmospheric pollution (0.33–0.55 mg SO_4/dm^2/day + 21–40 kg metals/ha/a			Very heavy pollution (more than 0.55 mg SO_4/dm^2/day + more than 40 kg metals/ ha/a		
		Biocenose destruction	Barren ground formation	Desert formation	Biocenose destruction	Barren ground formation	Desert formation
SO_2 and metal dust emissions		75–77	80–83		50–60	65–70	75
SO_2 and metal dust emissions	Clear cuttings + recreation	55–60	61–63	72–75	45–48	54–58	62–65
	Recreation + ground fire	44–47	53–57	59–62	36–40	44–47	50–53
	Recreation + clear cuttings + fire	35–37	43–45	50–54	30–33	38–40	44–47
	Recreation + household pollution + clear cuttings + fire	33–36	38–41	42–46	24–28	33–35	37–40

Conclusions

1. Thus, all earlier data on degradation and destruction of forest ecosystems in the zone of pollutant impact simplify without considering and estimation of other factors' role the situation and distort it to a certain extent.
2. The negative consequences of emission impacts could be considerably less if a combination of measures were used to regulate territorial development.
3. Among the factors accompanying emissions, the most destructive for spruce stands are ground fires as well as fires and unregulated cuttings.
4. Processes of degradation, ecosystem death and technogenic transformation of ecotones were clearly exponential in character. The curve "dose-effect" is S shaped because of the buffering capacity of the ecosystem.
5. The fastest ecotone transformation took place after the death of the biogeocenose – the final stages of the destruction of the natural complex.

References

Doncheva, A.V. 1978. Landshaft v zone vozdeistvia promyshlennosti. Moskva. Lesnaja promyshlennost. 97 p.

Lesnai ekosistema i atmosfernye zagriaznenia. 1990. Nauka, Leningrad. 198 p.

Karpenko, A.D. 1981. Ocenka sostoiania drevostoev, nachodiashichsia pod vozdejstviem promyshlennych emissii. Ekologija i zashita lesa 6:39–43.

Kryuchkov, V.V. 1985. Ohrana prirody Severa. Problemy antropogennogo vozdeistvia na okrugaushui sredu. Nauka, Moskva. p. 124–131.

Nikonov, V.V. & Lukina, N.V. 1989. Organizacia, technogennaia transformacia i optimizacia ispolzovania lesov na severnom predele rasprostranenia. Problemy kompleksnogo ispolzovania prirodnych resursov. p. 105–106.

Tsvetkov, V.F. 1990. Povregdenie lesov promyshlennymi vybrosami medno-nikilevogo kombinata v Murmanskoi oblasti. Botanicheskie issledovania za Poliarnym Krugom. NS RAN, Kirovsk. p. 185–196.

Possible influence of air pollution on endophytic fungi in Norway spruce needles

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Abstract

Norway spruce needles collected in polluted and non-polluted areas in central Europe and northern Fennoscandia were examined for fungi. Two widespread endophytic fungi, *Lophodermium piceae* (Fuck.) Höhn. and *Tiarosporella parca* (Berk. and Br.) Whitney, Reid & Pirozynski occurred in Norway spruce (*Picea abies* (L.) H. Karst.) needles. The most common of these, *L. piceae*, was rare or had disappeared in areas with severe air pollution while *T. parca* seems to have been less affected. *T. parca*, which was earlier considered to be rare, is now thought to be rather widespread in European spruce forests. It appeared to be rather common in northern Fennoscandia and is recorded here for the first time from Finland.

Introduction

Endophytic fungi have been found in association with numerous plant groups and although their role is still unclear, it has been shown that they may produce antifungal and antibacterial compounds (Fisher *et al.* 1984). Beginning with the studies of Bernstein & Caroll (1977) on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), endophytic fungi of living needles of various conifers have been thoroughly studied over the past 15 years in both Europe and North America. Needles of Norway spruce (*Picea abies* (L.) H. Karst.) have been studied in many countries and *Lophodermium piceae* (Fuck.) Höhn. has been found to be the most common endophyte (Barklund & Rowe 1983, Schütt 1985, Butin 1986, Barklund 1987, Sieber 1988, Suske & Acker 1988, Mack 1989). Another endophytic fungus, *Tiarosporella parca* (Berk. & Br.) Whitney, Reid & Pirozynski is also common in some areas (Sieber 1988, Heiniger & Schmidt 1989, Mack 1989).

Rehfuess & Rodenkirchen (1984) assumed that *L. piceae* could be a contributing factor in the syndrome of air pollution and forest decline. However, Schütt (1985) did not agree with their conclusions. Later studies by Butin & Wagner (1985) and Butin (1986) supported this position. In addition, Barklund & Rowe (1983) in Sweden observed that *L. piceae* was less abundant in green needles in areas receiving large amounts of acid rain.

When studying the litterfall from permanent plots of the Norwegian monitoring programme for forest damage, Solheim (1988, 1989) noted that *L. piceae* was absent in Mellesmo, Pasvik, in northeastern Norway and replaced by another endophyte, *T. parca*. The plot in Mellesmo is a heavily polluted area near emission sources in Russia (SO_2 and heavy metals). However, besides air pollution other factors could also account for the absence of *L. piceae* there, e.g., the natural spruce forest in Pasvik is dominated by *P. abies* var. *obovata* (Ledeb.) C. Koch, not by var. *abies* as in the other plots, and the climate in Pasvik differs from that in other plots in Norway (Solheim 1988, 1989).

The purpose of this study was to collect more knowledge about the role of air pollution and endophytic fungi and especially about the absence of *L. piceae* in Mellesmo, Pasvik.

Material and methods

In 1989, northern parts of Fennoscandia, i.e. Sweden in July and Finland and Norway in September, were visited. All the stands (Fig. 1) were old, naturally regenerated Norway spruce containing trees of various ages, except a few stands in Pasvik, Norway which consisted of younger plantations. The old stands in Pasvik are small with few trees, and at Krokvik only one tree was found. Based on cone scales (Lid 1974) the trees were identified as *Picea abies* var. *obovata* or var. *abies*. However, in areas where both spruce varieties were common specific identifications were uncertain.

Needles were collected on the ground under three to four trees in all the stands which were visited and afterwards they were examined for fungi using either a stereomicroscope or a compound microscope. In northern Finland, needles with needle reddening were also collected from two to three branches up to 7 m above ground in each stand. Green needles for isolation of endophytes (Rack & Butin 1984) were taken from branches cut off about 6 m above ground in all stands in Pasvik, Norway and in three stands in northern Finland. From each stand 40 or 50 needles were collected. Green needles, from the same branches, were used to determine their content of mineral elements (Ogner *et al.* 1991).

In August–September, 1989 we visited areas in central Europe with severe forest decline, i.e., the Black Forest, the Bavarian Forest and Harz in Germany, and Erzgebirge in Czechoslovakia. In these forests needles were collected on the ground under three to four trees in Norway spruce stands. In a few localities green needles were taken for chemical analysis.

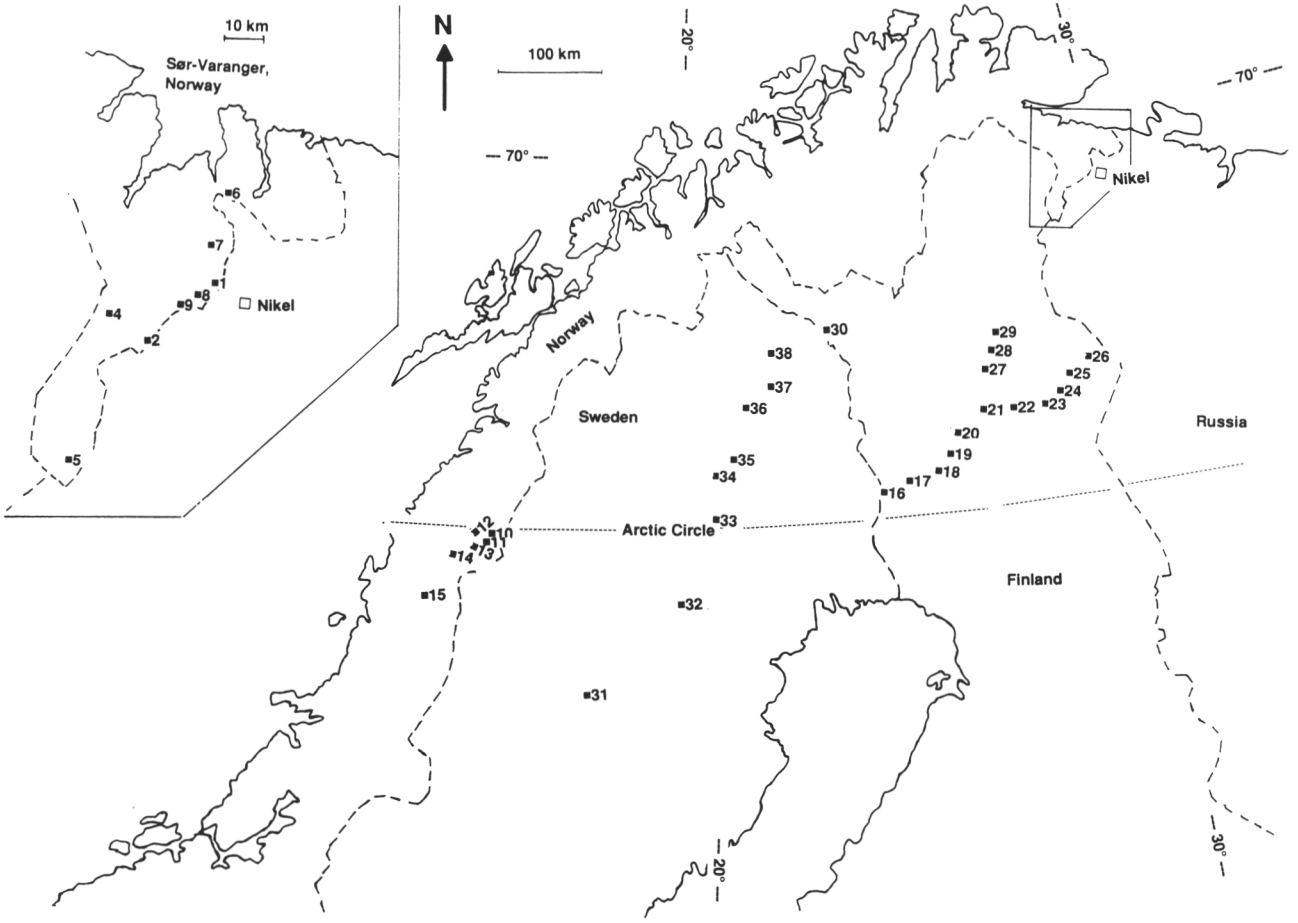

Fig. 1. Location of sample plots in northern Fennoscandia. The numbers correspond to numbers in Tables 1–4.

Results

Observations in northern Fennoscandia

Pasvik

Examination of needles collected on the ground showed that both *L. piceae* and *T. parca* were present in Pasvik (Table 1). *T. parca* was most common in stands with old *P. abies* var. *obovata* trees, while *L. piceae* was most common in stands with planted *P. abies* var. *abies*. *L. piceae* was not found in Krokvik and Mellesmo (Table 1). Isolations from green needles revealed a similar pattern. In the planted stands with var. *abies*, only *L. piceae* was isolated, while both *L. piceae* and *T. parca* were isolated in the old stands with var. *obovata* except in Krokvik and Mellesmo where only *T. parca* was found. The chemical analyses revealed that Mellesmo is heavily influenced by air pollution, for instance the sulphur content of needles was 63 mmol/kg. The sulphur content in needles in the other localities ranged from 30 to 52 mmol/kg (Table 1).

Table 1. Frequency of *Lophodermium piceae* and *Tiarosporella parca* and other fungi on Norway spruce needles collected on the ground in Pasvik, northern Norway, and the sulphur (S), copper (Cu) and iron (Fe) content of three year-old green needles from branches taken about 6 m above ground.

Sites	*L. piceae* %	*T. parca* %	Other fungi %	Content of (mmol/kg) S	Cu	Fe
Old spruce stands[a]						
1 Mellesmo	0	33	30	63	0.098	2.0
2 Krokvik	0	57	13	48	0.057	1.4
3 Sagvasslomba	32	35	18	36	0.039	1.0
4 Oksvatn	8	12	25	30	0.045	0.9
5 Tommamyra	7	44	20	34	0.036	1.3
Plantations[b]						
6 Pikevatn	21	7	40	43	0.077	2.4
7 Skrukkebuktvatn	64	2	15	44	0.049	1.7
8 Salmovara	19	2	64	52	0.053	1.2
9 Grandalen	57	6	19	30	0.048	0.7

[a] With *Picea abies* var. *obovata*
[b] With *Picea abies* var. *abies*

Table 2. Frequency of *Lophodermium piceae* and *Tiarosporella parca* and other fungi on Norway spruce needles collected on the ground in Helgeland, northern Norway.

Sites[a)]	*L. piceae* %	*T. parca* %	Other fungi %
10 Bolna	42	0	65
11 Krokstrand	33	0	72
12 Storvoll	58	3	26
13 Dunderland	36	1	43
14 Mo	61	0	38
15 Tustervann	48	0	27

[a)] All stands with old trees of *Picea abies* var. *abies*.

Helgeland

In Helgeland, where needles were collected in old stands of *P. abies* var. *abies*, *L. piceae* was rather common (Table 2). *T. parca* occurred randomly in two of the stands.

Northern Finland

The spruce trees in the stands in northern Finland were mostly *P. abies* var. *obovata*. *L. piceae* was more common than *T. parca* in all stands except one (Table 3). However, *T. parca* was present in all stands, where it was often associated with needle reddening. Isolations from green needles from three stands showed both *L. piceae* and *T. parca* to be common endophytes. These three stands are less affected by air pollution than most stands in Pasvik (Table 3).

Northern Sweden

L. piceae was more abundant than *T. parca* in all stands except one in northern Sweden (Table 4). However, *T. parca* was rather common. The variety of Norway spruce was not determined.

Observations in Central Europe

Germany

L. piceae was found in most of the Norway spruce stands examined in Germany, but there were great differences between stands within the same area (Table 5). *L. piceae* was less abundant in areas with a higher degree of air pollution (Fig. 2). *T. parca* was also present in most sites in Germany, but its frequency varied (Table 5).

Czechoslovakia

L. piceae was rather rare in the highly polluted area of Erzgebirge, while *T. parca* was common (Table 6).

Table 3. Frequency of *Lophodermium piceae* and *Tiarosporella parca* and other fungi on Norway spruce needles collected on the ground in northern Finland, and frequency of *T. parca* on needles with "needle reddening", and the sulphur (S), copper (Cu) and iron (Fe) content in three years old green needles from branches taken about 6 m above ground.

	Needles on the ground			Needle reddening			
	L. piceae	*T. parca*	Other fungi	*T. parca*	Content of (mmol/kg)		
Sites	%	%	%	%	S	Cu	Fe
16 Pello	61	12	21	–	26	0.033	2.9
17 Ruuhijärvi	67	7	17	–	–	–	–
18 Meltaus	51	10	21	57	–	–	–
19 Laitavaara	58	10	29	18	–	–	–
20 Syväjärvi	76	2	19	1	–	–	–
21 Sodankylä	70	2	33	3	35	0.027	0.7
22 Kelujärvi	67	3	21	44	–	–	–
23 Värriö	68	3	13	48	–	–	–
24 Martti	51	1	22	23	–	–	–
25 Lattuna	66	6	14	50	–	–	–
26 Tulppio	27	7	44	40	30	0.032	0.8
27 Peurasuvanto	49	27	19	41	–	–	–
28 Siltaharju	50	12	18	0	–	–	–
29 Vuotso	51	7	32	0	–	–	–
30 Palojoensuu	7	42	32	20	–	–	–

– = Not analysed

Table 4. Frequency of *Lophodermium piceae* and *Tiarosporella parca* and other fungi on Norway spruce needles collected on the ground in northern Sweden.

Sites	*L. piceae* %	*T. parca* %	Other fungi %
31 Storuman	35	31	22
32 Moskosel	67	17	19
33 Jokkmokk	55	2	21
34 Muddus	49	32	40
35 Gällivare	65	13	19
36 Svappavaara	24	21	39
37 Saappisaasi	57	18	44
38 Övre Sopporo	9	41	59

Table 5. Frequency of *Lophodermium piceae* and *Tiarosporella parca* and other fungi on Norway spruce needles collected on the ground in Germany, and sulphur (S), copper (Cu) and iron (Fe) content in three year-old green needles.

Sites	*L. piceae* %	*T. parca* %	Other fungi %	Content of (mmol/kg) S	Cu	Fe
Harz						
Ackerbrockenberg	0	23	15	–	–	–
"	6	8	24	–	–	–
Lange Branke	66	1	17	43	0.045	1.8
"	15	6	21	–	–	–
Schwarzwald						
Schauinsland	9	29	11	–	–	–
Staufen	18	69	20	–	–	–
Glaserwald	19	8	27	–	–	–
Haldenhof	30	0	31	–	–	–
Bayerische Wald						
Luchsplatz	12	2	33	–	–	–
Neuhütte	27	7	51	43	0.066	1.8
"	89	1	17	38	0.063	1.7
Marktredwich	3	12	39	–	–	–
"	9	9	39	–	–	–
Goslar	2	14	12	–	–	–
"	5	7	18	–	–	–

– = Not analysed

Table 6. Frequency of *Lophodermium piceae* and *Tiarosporella parca* and other fungi on Norway spruce needles collected on the ground in Czechoslovakia, and the sulphur (S), copper (Cu) and iron (Fe) content in three years old green needles.

Sites	*L. piceae* %	*T. parca* %	Other fungi %	Content of (mmol/kg) S	Cu	Fe
Flaje	1	14	42	94	0.057	3.3
Hora Sv.-Sebastiana	2	21	39	–	–	–
"	2	24	33	–	–	–
Krasno	0	16	35	–	–	–
Konlog Varg	1	23	30	–	–	–

– = Not analysed

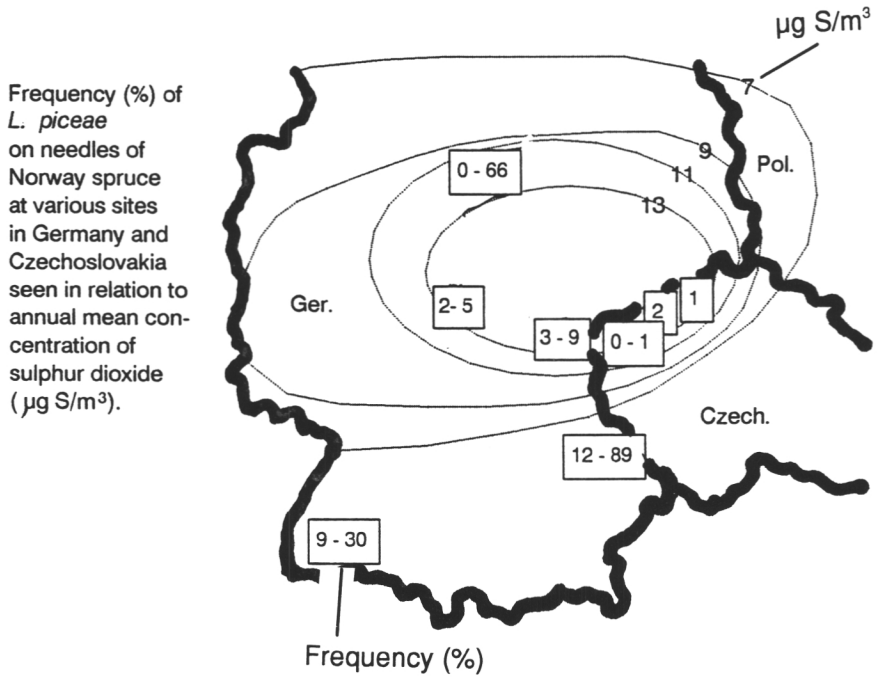

Fig. 2. Percent *Lophodermium piceae* on needles of Norway spruce at various sites in Germany and Czechoslovakia as related to the annual mean concentration of sulphur dioxide in the atmosphere (µg S/m³) according to Schaug *et al.* 1989.

Discussion

The results of this preliminary study support the findings of Solheim (1988, 1989) who found that *L. piceae*, the most common endophyte in Norway spruce needles, was absent in Mellesmo, Pasvik. Moreover, our results showed that *L. piceae* was present in the needles of both the *abies* and *obovata* varieties of Norway spruce in many sites in Pasvik and that it was also common in other areas in northern Fennoscandia. Except for a single tree in Krokvik, *L. piceae* was absent only in Mellesmo, Pasvik. Mellesmo is much more affected by air pollution than the other sites. The samples from central Europe strongly supported that the presence of *L. piceae* is negatively affected by air pollution. However, since the abundance of *L. piceae* may vary among trees and stands (Butin 1986, Barklund 1987, Sieber 1988, Mack 1989), additional studies should be made.

The influence of air pollution on fungi growing on plant foliage is documented (e.g. Huttunen 1984). In Poland, Grzywacz & Wazny (1973) showed that *Lophodermium pinastri* (Scrad. ex Hook.) Chev. and other fungi were strongly inhibited close to emission sources. There the

abundance of certain fungi was highest in areas with moderate pollution and decreased slightly further away from the emission sources. Kowalski (1981) found a similar situation when studying *Lophodermium seditiosum* Minter, Staley & Millar on Scots pine (*Pinus sylvestris* L.) in Poland. Also Heliövaara *et al.* (1989) who studied *Lophodermium* species on Scots pine in relation to air pollution in Finland, found that *Lophodermium* species suffered air pollution.

Tiarosporella parca seems to tolerate more air pollution than *Lophodermium piceae*, since it was rather common in highly polluted areas. Until recently *T. parca* has been recorded only rarely in Europe (Whitney *et al.* 1975). Studies on needle cast associated with air pollution on Norway spruce have revealed that this fungus is rather widespread in Europe, e.g., in Switzerland (Heiniger & Schmid 1986, 1989, 1990, Sieber 1988) and Norway (Solheim 1988, 1989), and it has also been found a few times in Austria (Cech & Tomiczek 1988), Czechoslovakia (Whitney *et al.* 1975), Germany (Rack & Butin 1984, Mack 1989) and Sweden (Livsey & Barklund 1992). In our study, *T. parca* was found in most sites in Czechoslovakia, Germany, Finland, Norway and Sweden, which seems to indicate that this fungus is widespread in all Norway spruce forests in Europe. The records are new for Finland.

Heiniger & Schmid (1990) speculated as to why *T. parca*, which was earlier thought to be a rare fungus, is now found widely, i.e., *T. parca* has likely always been present, but it has not been recognized because (i) the fruit bodies are produced late in the season, (ii) the pycnidia disappear or are overgrown by other fungi in the forest litter, (iii) the fungus is not present in young trees and (iv) the fungus sporulates erratically in culture. We agree with these ideas, but the fungus is not difficult to recognize on needles in the litter. On old needles from the ground pycnidia are often empty and their black color has nearly disappeared. When examining such needles by eye it may be difficult to distinguish between *T. parca* and the *Leptostroma* anamorph of *L. piceae*. However, their location within needles is characteristic, and they can easily be distinguished by using a microscope. The pycnidia of *T. parca* are circular to elliptical with two layers of epidermal cells above them (Whitney *et al.* 1975). The pycnidia of *L. piceae* are oblong in cross-section, never deep in the needles, and only rupture the first row of needle epidermal cells. Often both fungi occur on the same needle and then they are separated by black crosslines.

Acknowledgements

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References

Barklund, P. 1987. Occurrence and pathogenicity of Lophodermium piceae appearing as an endophyte in needles of Picea abies. Transaction of the British Mycological Society 89: 307–313.

— & Rowe, J. 1983. Endophytic fungi in Norway spruce – possible use in bioindication of vitality. Aquilo Series Botanica 19: 228–232.

Bernstein, M.E. & Carroll, G.C. 1977. Internal fungi in old-growth Douglas fir foliage. Canadian Journal of Botany 55: 644–653.

Butin, H. 1986. Endophytische Pilze in grünen Nadeln der Fichte (Picea abies Karst.). Zeitschrift für Mykologie 52: 335–346.

— & Wagner, C. 1985. Mykologische Untersuchungen zur "Nadelröte" der Fichte. Forstwissenschaftliche Centralblatt 104: 178–186.

Cech, T. & Tomiczek, C. 1988. Tiarosporella parca (Berk. and Br.) Whitney – erster Nachweis in Österreich. European Journal of Forest Pathology 18: 382–384.

Fisher, P.J., Anson, A.E. & Petrini, O. 1984. Antibiotic activity of some endophytic fungi from ericaceous plants. Botanica Helvetica 94: 249–253.

Grzywacz, A. & Wazny, J. 1973. The impact of industrial air pollutants on the occurrence of several important pathogenic fungi of forest trees in Poland. European Journal of Forest Pathology 3: 129–141.

Heiniger, U. & Schmid, M. 1986. Nadelfall der Fichte. Schweizer Zeitschrift für Forstwesen 137: 157–162.

— & Schmid, M. 1989. Association of Tiarosporella parca with needle reddening and needle cast in Norway spruce. European Journal of Forest Pathology 19: 144–150.

— & Schmid, M. 1990. Occurrence of Tiarosporella parca in Switzerland: A cause of needle blight? In: Merrill, W. & Ostry, M. E. (eds.). Recent research on foliage diseases. Conference proceedings, Carlisle, Pennsylvania. May 29 – June 2, 1989. USDA Forest Service General Technical Report WO-56. p. 65–68.

Heliövaara, K., Väisänen, R. & Uotila, A. 1989. Hysterothecia production of Lophodermium species (Ascomycetes) in relation to industrial air pollution. Karstenia 29: 29–36.

Huttunen, S. 1984. Interactions of disease and other stress factors with atmospheric pollution. In: Treshow, M. (ed.). Air pollution and plant life. Chichester. p. 321–356.

Kowalski, T. 1981. Fungi infecting needles of Pinus sylvestris in Poland in relation to air pollution zone. In: Millar, C. S. (ed.). Current research on conifer needle diseases. Proc. IUFRO Working Party on needle diseases, Sarajevo 1980. p. 93–98.

Lid, J. 1974. Norsk og svensk flora. Det norske samlaget, Oslo. 808 p.

Livsey, S. & Barklund, P. 1992. Lophodermium piceae and Rhizosphaera kalkhoffii in fallen needles of Norway spruce (Picea abies). European Journal of Forest Pathology 22: 204–216.

Mack, P. 1989. Endophytische Pilze in Fichtennadeln. Dissertation Forstwissenschaftlichen Fakultät der Ludwig-Maximilians-Universität, Munich. 124 p. + appendix.

Ogner, G., Opem, M., Remedios, G., Sjøtveit, G. & Sørlie, B. 1991. The chemical analysis program of the Norwegian forest research institute 1991. Norsk institutt for skogforskning. Ås. 21 p.

Rack, K. & Butin, H. 1984. Experimenteller Nachweis nadelbewohnender Pilze bei Koniferen. I. Fichte (Picea abies). European Journal of Forest Pathology 14: 302–310.

Rehfuess, K.E. & Rodenkirchen, H. 1984. Über die Nadelröte-Erkrankung der Fichte (Picea abies Karst.) in Süddeutschland. Forstwissenschaftliche Centralblatt 103: 248–262.

Schaug, J., Skjelmoen, J.E., Walker, S.E., Petersen, U. & Harstad, A. 1989. Data report 1987. Part 1: Annual summaries. Lillestrøm, NILU: EMEP Chemical Co-ordinating Centre, 1989. (EMEP/CCC 1/89). 184 p.

Schütt, P. 1985. Das Waldsterben – eine Pilzkrankheit? Forstwissenschaftliche Centralblatt 104: 169–177.

Sieber, T. 1988. Endophytische Pilze in Nadeln von gesunden und geschädigten Fichten (Picea abies (L.) Karsten). European Journal of Forest Pathology 18: 321–342.

Solheim, H. 1988. Fungi on spruce needles in Norway. I. Litterfall samples from the permanent plots of the Norwegian monitoring program for forest damage in 1986. Agarica 9: 55–60.

— 1989. Fungi on spruce needles in Norway. II. Notes about Tiarosporella parca. European Journal of Forest Pathology 19: 189–191.

Suske, J. & Acker, G. 1988. Internal hyphae in young, symptomless needles of Picea abies: electron microscopic and cultural investigation. Canadian Journal of Botany 65: 2098–2103.

Whitney, H.S., Reid, J. & Pirozynski, K.A. 1975. Some new fungi associated with needle blight of conifers. Canadian Journal of Botany 53: 3051–3063.

Genetic variation of *Gremmeniella abietina* in Finland

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Abstract

Differences between two *Gremmeniella abietina* types in Finland are described.

Introduction

Gremmeniella abietina (Lagerb.) Morelet has been divided into three races: European, North-American and East-Asian (Dorworth & Krywienzyk 1975). Morelet (1980) separated *G. abietina* var. *cembrae*. Kujala (1950) and Roll-Hansen & Roll-Hansen (1973) have observed that in southern Finland and southwestern Norway the fungus produces abundant pycnidia instead of abundant apothecia as is the case in northern regions. In addition to geographical variation, the strains of *G. abietina* isolated from the same ascus can vary e.g. in external appearance of the colony or in conidial production in culture (Uotila 1990). Two types of *G. abietina*, A and B seem to occur in Finland (Uotila 1983). B type resembles *G. abietina* var. *cembrae*.

Comparison of the types A and B

In southern Finland the type A occurs in Scots pine (*Pinus sylvestris* L.) stands of all ages. In older trees it usually infects only lower branches, but in pole-stage stands it often infects leader shoots, too. Type A also kills seedlings growing under larger pines and nursery seedlings. In northern Finland it occurs in pole-stage or older pines. However, the damage of type A has not been as common in northern Finland as in southern Finland. Cankers on the stem and branches are common to both types. Both types have the same life cycle.

Type B is common from North Karelia to Lapland. It infects pine seedlings 0–2 m in height in the forest and nurseries. It appears that seedlings becoming saplings, ie. protruding over the snow cover suffer the most. Apothecia occur abundantly in the stems of dead seedlings two years after infection. Pycnidia can be found in dead shoots already one year after infection.

Type A has 4-celled conidia and type B 4 to 8-celled ones (Fig. 1). This difference is genetically determined, because the same difference has been observed in nature and in laboratory cultures. Type B produces more conidia than type A in cultures (Uotila 1990). Main conidial structure is 4-celled in both types, but the frequency of 5, 6, 7 and 8-celled conidia is significantly higher in type B than type A. However, the proportion of 7 to 8-celled conidia in type B was not so high as in some *G. abietina* var. *cembrae* isolates (Uotila 1983). Conidia are longer in type B than type A (Fig. 2). In nature the number of short conidia is lower in both types, because some strains produce deformed and short conidia in cultures.

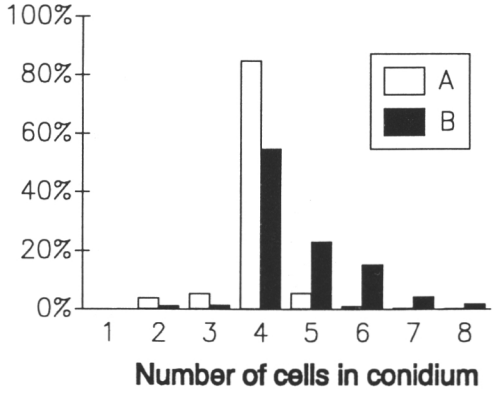

Figure 1. The cell number distribution of conidia grown in monoascospore cultures of type A and B strains on barley + pine needle medium.

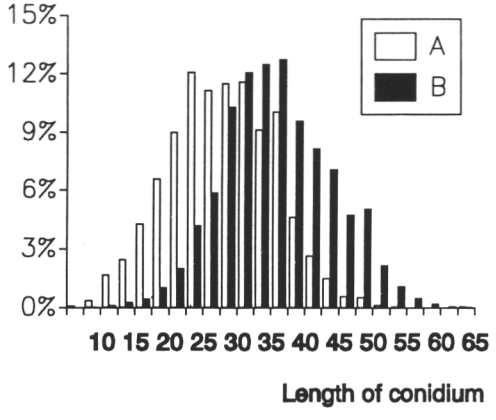

Figure 2. The distribution of conidium length in the A and B types. It was measured from 2565 conidia belonging to type A, and 5940 conidia belonging to type B.

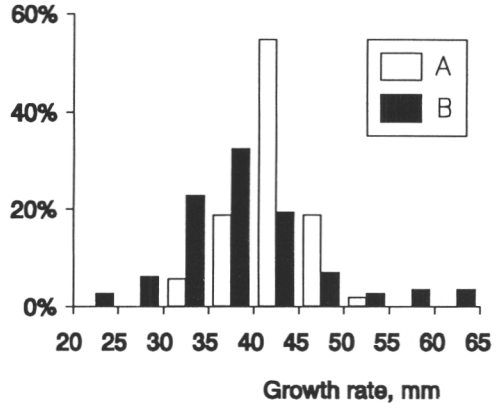

Figure 3. The colony diameter distribution of type A and B strains 42 days after monoascospore isolation. The mycelia were grown on 1 % malt agar + needle extract at 15 °C. The growth rates were measured from 50 type A and 114 type B cultures.

The external appearance of the colony outlook varies individually, but type A colonies on needle extract malt agar are usually fluffy because they have a lot of aerial mycelium. The mycelia of the type A grow slightly faster than type B at 15 °C (Uotila 1983). More recent results for monoascospore cultures are in agreement with this, but the variation among single ascospore cultures is very wide in type B. The variation in the growth rate of type A is rather narrow (Fig. 3).

The protein composition of type B resembles *G. abietina* var. *cembrae*, and the protein composition of type A is the same as in the European race (Petrini *et al.* 1990).

The occurrence of types A and B in different kinds of stand means that there may be differences in pathogenicity or in the behaviour of the fungus.

Apothecia production of types A and B differed genetically because in pairing experiments the differences in apothecia production were independent of the climatic conditions at two experimental sites (Uotila 1992).

Both types are heterothallic and mating is controlled by one locus. Type B can also produce some apothecia in incompatible pairings, which means that factors other than the mating locus can also affect apothecia production (Uotila 1992).

Conclusions

Type A can be considered to be the typical European race. Although type B resembles *G. abietina* var. *cembrae*, it is not quite the same. It appears that type B is more heterogeneous in some characteristics

than type A. This is natural because type B spreads primarily via ascospores, and type A by means of conidia. The differences between types A and B are probably caused by different gene distribution. Intermediate isolates may exist. Crossings between types A and B at least, have produced apothecia in pairing experiments (Uotila 1992). If further experiments show clear differences in pathogenicity between the types, the quarantine orders for nursery seedlings could be used to hinder the spread of a virulent race to new areas.

References

Dorworth, C.E. & Krywienzyk, J. 1975. Comparisons among isolates of Gremmeniella abietina by means of growth rate, conidia measurement and immunogenic reaction. Canadian Journal of Botany 53(21): 2506–2525.

Kujala, V. 1950. Über die Kleinpilze der Koniferen in Finnland. Communicationes Instituti Forestalis Fenniae 38(4). 121 p.

Morelet, M. 1980. La maladie a Brunchorstia: I. Position systematique et nomenclature du pathogene. European Journal of Forest Pathology 10: 268–277.

Petrini, O., Toti, L., Petrini, L.E. & Heiniger, U. 1990. Gremmeniella abietina and G. laricina in Europe – characterization and identification of isolates and laboratory strains by soluble protein electroforesis. Canadian Journal of Botany 68(12): 2629–2635.

Roll-Hansen, F. & Roll-Hansen, H. 1973. Scleroderris lagerbergii in Norway. Hosts, distribution, perfect and imperfect state and mode of attack. Meddelelser fra Det Norske Skogforsøksvesen 30: 443–459.

Uotila, A. 1983. Physiological and morphological variation among Finnish Gremmeniella abietina isolates. Communicationes Instituti Forestalis Fenniae 119. 12 p.

— 1990. Variation in uniascus monoascospore cultures of Ascocalyx abietina. Metsäntutkimuslaitoksen tiedonantoja 360: 67–73.

— 1992. Mating system and apothecia production in Gremmeniella abietina. European Journal of Forest Pathology 22: 410–417.

Gremmeniella abietina in NW Russia

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Abstract

Data on the distribution of *Gremmeniella abietina* (Lagerb.) Morelet injuring plantations of *Pinus sylvestris* L. and *P. cembra* L. (subsp. *sibirica*) in the taiga zone of the European part of Russia (Karelia, Komi, Murmansk, Arkhangelsk and St. Petersburg regions) are given. Relationships between the distribution of the damage and the geographical origin of the seeds and the application of mineral fertilizer are discussed.

Introduction

High-intensity, rapid reforestation of the forests following intensive cuttings is one of the main problems in the European part of Russia including the regions of Karelia and Murmansk. This has necessitated the use of both planting as well and natural regeneration of conifers. Thus, during the period 1976–1985 the annual amount of planting in Karelia averaged c. 50 000 hectares. Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) were the species mostly in establishing these plantations. Until recently, direct sowing of felling sites was used as the main method of artificial regeneration. For this purpose great volumes of seeds were imported to Karelia from various geographical points ranging from Byelorussia to the Amur region because of constant shortages (due to infrequent seed years) of local Karelian conifer seed, particularly of pine. However, it is well known that the productivity and quality of forest plantations and their resistance to stress factors (including fungal diseases) depend very much on the origin of the seed used.

In 1982 the directive "The rules for using seeds for forest plantations in various regions of the USSR" controlling the storage and usage of seed for sowing was put into practice. It led to a fall in the overall amount of artificial regeneration carried out. Moreover, in recent years the proportion of plantations established using planting stock raised in nurseries in Karelia increased up to 50 percent. In lesser amounts this practice has been applied in the Murmansk region, too.

Material and methods

The objects of the investigations were 1 to 3 year-old sowings of *P. sylvestris* in nurseries and plantations of *P. sylvestris* of 1 to 26 years of age established both by sowing and planting in ecologically different sites on new and old clear cutting areas throughout the regions of Karelia and Murmansk.

General surveys as well as detailed examinations of every tree on the sample plots were used. Depending on the size of the felling area, one to five temporary sample plots 50 m × 50 m, or 50 m × 10 m, or 25 m × 20 m in size were established. The size of the sample plots was based on stand density. Each of the sample plots contained no less than 100 live or dead trees. Permanent sample plots 25 m × 20 m in size were placed only in plantations chosen for monitoring. Complete descriptions were made of the trees, undergrowth, grasses, mosses, soils, etc., on every sample plot. The main biometric characteristics were estimated for every tree on these sample plots. Observations were also made of the state of health of the trees, the proportion of dead trees and the reasons for it, the species composition of the pathogens and the extent of damage caused by them depending on factors such as ecological conditions, methods of planting, origin of seeds, density of the plantations, character of development, age, etc.

Results

Distribution and damage

The *Scleroderris* canker (the causal organism is the ascomycete *Gremmeniella abietina* (Lagerb.) Morelet and its conidial stage *Brunchorstia pinea* (Karst.) v. Höhnel) is a comparatively new, little known disease of conifers in the northern parts of European Russia. Data on the occurrence, pathogenicity and the biology and ecology of its causal organism in this region were practically nonexistent up to the 1970's, whereas in the Nordic and Central European countries this disease has been mentioning since the end of the last century.

As a common and widely distributed disease of coniferous plantations of various age, the *Scleroderris* canker was first reported by Krutov (1979) during a detailed survey of young coniferous stands in the Murmansk district in 1965 and 1967 (Fig. 1). The proportions of 3–5 year-old seedlings killed by this disease averaged 4 % for the northern and 9 % for the southern parts of the region with the largest mortality (up to 60 %) occurring in 15 to 17 year-old plantations. Extensive damage to 8 year-old experimental sowings (12–24 %) and in particular to plantings with seeds and seedlings from the southern Karelia planted in the furrows of partly cultivated soils (11–60 %) took place in 1977 in the south of the region. By 1988 these plantations

were completely dead. In all cases the causal organism was present in both anamorph (*B. pinea*) and ascomycete (*G. abietina*) forms. The latter was more frequent, and this corresponds with data from Finland and Norway (Kujala 1950, Roll-Hansen & Roll-Hansen 1973). Slight damage to 3 year-old seedlings by *B. pinea* ranging from single seedlings to ten percent was noticed in some forest tree nurseries in Karelia almost at the same time (1967, 1972, 1977).

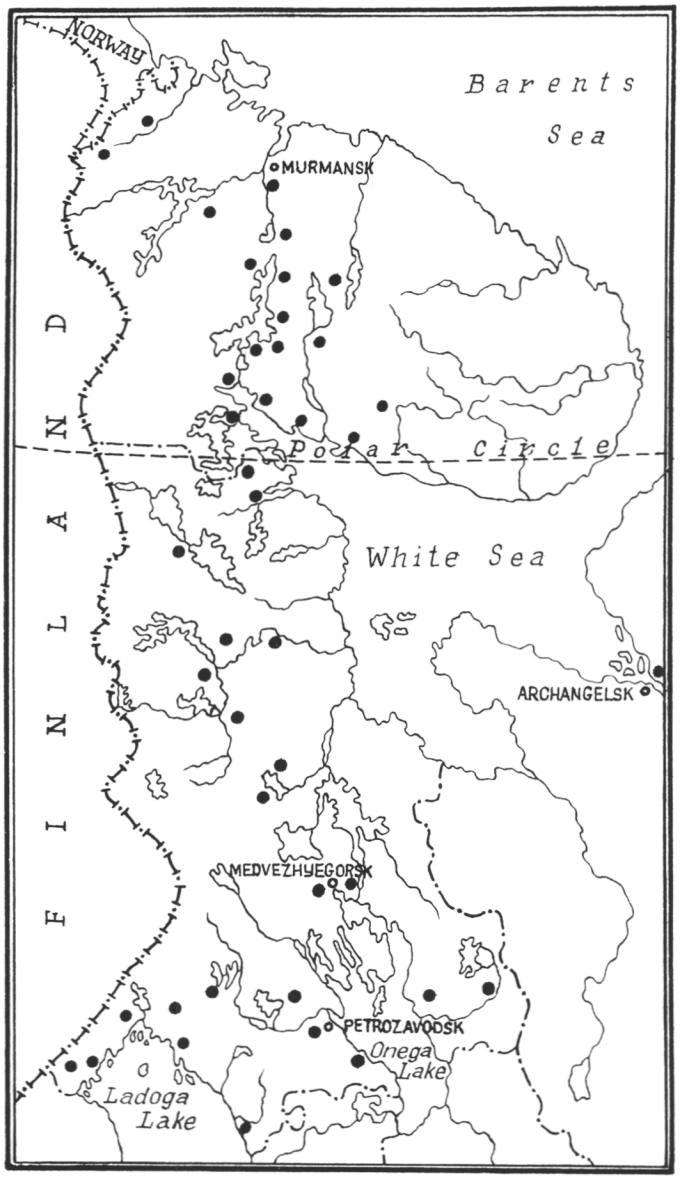

Figure 1. Occurrence of the *Scleroderris* canker in the regions of Karelia, Murmansk and Arkhangelsk.

On the cutting areas of Karelia, the *Scleroderris* canker has not so far been considered to be a dangerous disease although serious damage caused by it (21–23 % distribution, 11–13 % loss) have been observed in experimental sowings of 14 year-old Scots pine on clear cutting areas (burnt-after-cutting pine heath) in southern Karelia where fertilization with nitrogen and potassium ($N_{60}K_{60}$) or potassium (K_{60}) fertilizers has been carried out for nine years. Indices of the degree of damage caused by it in the control were 11 % and 2 % respectively. Death of industrial plantations of *P. sylvestris* established in 1971–1974 as a result of mass injury caused by the *G. abietina* and snow blight (*Phacidium infestans* L.) was observed in 1981 in the northern parts of Karelia over an area of several hundred hectares. Both pathogen stages were also present in young pine stands in Karelia but the conidial stage (*B. pinea*) predominated in the indicated localities of the disease.

As mentioned above, seeds brought from various geographical regions of the USSR were mainly used to establish stands by sowing in the Murmansk region and in the northern parts of Karelia because of the constant lack (due to infrequent seed years) of local pine seed. This is the major reason for the high pathogenicity of *G. abietina* as it is very rare on pines of local origin.

Similar data were obtained from the St. Petersburg region (Jakovlev *et al.* 1981). Within the St. Petersburg region there is considerable distribution of *B. pinea* causing the *Scleroderris* canker to become epiphytotic over tens of thousands of hectares of coniferous forest in 1971. Small local occurrences of the disease caused by the same pathogen were observed in 1979 on some sites of *P. sylvestris* and *P. cembra* L. with 12 % and 30 % (respectively) of the plants being killed (Jakovlev *et al.* 1981). According to the authors, the ascomycete stage of the pathogen was found very seldom. Single cases of *B. pinea* damage to 3 year-old seedlings of *P. sylvestris* were registered in forest tree nurseries in the Arkhangelsk region (Drachkov & Tyryshkina 1976). There are also some data on the frequent occurrence of the ascomycete stage of the pathogen in young pine stands in the Republic of Komi (Ivanova 1981), which, according to the author, develops as a saprophyte on dry and dying shoots without causing observable damage.

Diagnostic symptoms of the disease

According to some researchers, the development of the disease is characteristically connected with the availability of three pathogen races differing in their virulence (Dorworth & Krywienczyk 1975, Dorworth 1979). Fedorov (1978), while carrying out investigations on thirteen pine species introduced to Byelorussia, considers that the *Scleroderris* canker damage manifests itself varyingly in relation to the species of pine in question and the developmental stage (growth or

rest) of the host plant at the time of infection. Our investigations in nurseries and plantations of *P. sylvestris* in the regions of Karelia and Murmansk show that characteristics of the manifestation of the disease also greatly depend on the host plant's age and stage of development. The basis for this conclusion is provided by the occurrence of almost all *Scleroderris* canker symptoms indicated in literature ("umbrella", needle and shoot deformation, girdling or staged stem necrosis, top-dying, etc.) on one pine species under different ecological conditions and at different ages (Krutov 1989).

As the *Scleroderris* canker is a rather new disease in the territory of the former USSR and its symptoms are little known there, we have, together with Dr. M. Hanso, worked out some methodological recommendations on the diagnostics, prophylaxis and repelling measures to be applied by silvicultural specialists (Krutov & Hanso 1989). These recommendations were based on literature and the results of our own investigations.

References

Dorworth, C.E. 1979. Survey for detection of the European race of Gremmeniella abietina in Canada. Forest Research Newsletter Spring. 17 p.

— & Krywienczyk, J. 1975. Comparisons among isolates of Gremmeniella abietina by means of growth rate, conidia measurement and immunogenic reaction. Canadian Journal of Botany 53: 2506–2525.

Drachkov, V.N. & Tyryshkina, V.A. 1976. Bolezni sejantsev i mery borby s nimi v lesnyh pitomnikah Evropejskogo Severa. Materialy otchotnoj sessii po itogam nauchno-issledovatelskih rabot v devjatoj pjatiletke (1971–1975). Arkhangelsk. p. 60–62.

Fedorov, V.N. 1978. Patogennaja mykoflora hvojnyh introdutsirovannyh porod BSSR. Avtoreferat dissertatsii kandidata biologicheskih nauk. Minsk. 21 p.

Ivanova, E.A. 1981. Sostojanie i prichiny oslablenija molodnjakov sosny na belomoshnyh vyrubkah. Izvestija vuzov. Lesnoy Zhurnal 5: 23–27.

Jakovlev, V.G., Molotkova, N.D. & Lylov, A.P. 1981. Neobhodimost nadzora za rasprostraneniem v sosnovyh molodnjakah skleroderrievogo raka (Scleroderris lagerbergii Gremmen.). Nadzor za vrediteljami i boleznjami lesa i sovershenstvovanie mer borby s nimi. Moskva. p. 218–219.

Krutov, V.I. 1979. O parazitnoj mikoflore iskusstvennyh fitotsenozov sosny na vyrubkah Karelskoj ASSR i Murmanskoj oblasti. Mikologija i Fitopatologija 13(4): 345–349.

— 1989. Gribnye bolezni hvoinyh porod v iskusstvennyh tsenozah taejnoi zony Evropeiskogo Severa SSSR. Petrozavodsk. 208 p.

— & Hanso, M.E. 1989. Pobegovyi rak (skleroderrioz) sosny: diagnostika, profilaktika i mery borby. Petrozavodsk. 14 p.

Kujala, V. 1950. Über die Kleinpilze der Koniferen in Finnland. Communicationes Instituti Forestalis Fenniae 38(4). 121 p.

Roll-Hansen, F. & Roll-Hansen, H. 1973. Scleroderris lagerbergii in Norway. Hosts, distribution, perfect and imperfect state, and mode of attack. Meddelelser fra Det Norske Skogforsøksvesen 30(6): 443–459.

History of the decline in the Rikkilehto Scots pine stand

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Abstract

In 1988, *Gremmeniella abietina* (Lagerb.) Morelet was found to have damaged remote forests in eastern Lapland, Finland. One of the most infected stands was Rikkilehto, a 3.6 ha Scots pine stand in which 59 % of pines had died due to the pathogen. The description of the pathogen history with the help of the branch analysis showed that the pathogenic fungus had been in the stand as early as in the 1940's and continuously since the 1960's. Most tree mortality occurred in the 1980's before the area was discovered. In 1988–1990, a few new infections have happened in the Rikkilehto stand.

Introduction

Gremmeniella abietina (Lagerb.) Morelet has a long history in the *Pinus sylvestris* L. forests of Finnish Lapland. Damage was noticed as early as in the 1930's and 1940's in pine plantations (Kangas 1937, Kujala 1950). In the late 1960's, a serious epidemic occurred in nurseries (Kurkela 1967) and in young plantations (Norokorpi 1971). The peak of the epidemic occurred in 1969 in eastern Lapland and it was assumed to be induced by the cold summer of 1968 (Norokorpi 1972). Another epidemic occurred in 1982, especially at high elevations in central and eastern Lapland. Damage occurred in areas above the elevations of 250–270 m (Jalkanen 1987). This damage was assumed to be due to the cold and rainy summer of 1981 (Jalkanen 1984).

Since the summer 1988, several damaged areas have been found in eastern Lapland (Jalkanen & Kaitera 1992). The injured stands, mainly found by personnel of the Forest and Park Service, were concentrated on poor sites (70 % of observed cases), mineral soils (95 %), tills (82 %), in forests of first-thinning age (51 %) and in forests where the dominant tree species was Scots pine (87 %) (Kaitera & Jalkanen 1991). The total area of damaged forest was 1190.5 ha, which is 0.13 % of the total area of state forests in eastern Lapland. About 81 % of the total area was slightly damaged and 1.7 % severely damaged or totally destroyed (Kaitera & Jalkanen 1991). According to Salemaa *et al.* (1991), the worst injuries of the last epidemic occurred in 1988 and

since then no serious epidemics have occurred in eastern Lapland. However, an revival of the epidemic happened in autumn 1991.

The causes of the epidemic have been discussed in the press. The general opinion as to the cause of the *G. abietina* epidemic is in the huge sulphur dioxide emissions in the Kola peninsula. The Rikkilehto stand of 3.6 ha was also believed to be damaged by the high deposition of sulphur. Since 1988, scientists working in the Lapland Forest Damage Project have collected samples about the amounts of deposition in eastern Lapland. Private forest owners have also collected data about the SO_2 deposition near the study area in Naruska, Salla.

The aim of this study was to survey the injuries and to clarify the damage history in the case of the Rikkilehto stand. For this purpose, a new method based mainly on the presence of the cankers on branches and death of shoots, was developed (Kaitera & Jalkanen 1992). The role of pollution in the damage process was also discussed.

Material and methods

The Rikkilehto stand (67°12'N, 29°26'E) was inventoried in the autumn of 1990. Sample plots were placed along five lines from healthy forest up to and including the damaged area. The line and plot interval was 50 m, and the circular sample plot size was 100 m^2 (Fig. 1). *G. abietina* damage class was estimated on each sample plot according to the method presented by Hopkins *et al.* (1979). Breast height diameter, the *G. abietina* damage class according to Uotila (1985) and other possible agents of damage were recorded in each tree. A sample of the humus layer and the A horizon (0–10 cm) was taken from 4 points on every plot. The pH of the humus layer and the proportion of the small particles (ø < 0.06 mm) in the A horizon was analyzed. The elevations of the sample plots from Sätsi river were measured.

The damage history was determined from fourteen trees that represented different damage classes according to Uotila's (1985) classification. All the living and dead branches were collected for laboratory work. The number of scars and cankers caused by *G. abietina*, leader changes, the years when branches had died and the number of *Tomicus* attacks in each first-order branch were counted. The method for determining the *G. abietina* infections is described in detail by Kaitera & Jalkanen (1992), and the method for determining the *Tomicus* attacks by Kaitera & Jalkanen (1993b) (Fig. 2).

It is well known that *G. abietina* does not always kill the shoots immediately after the infection. Infection can lead to the formation of necrotic areas in the phloem of branches and stems (Kurkela 1981). Scars are points, where the fungus has not been able to expand. Cankers are points, where the fungus lives and expands year after year (Kurkela 1981). The wood underneath the canker at an infection point

is often yellow-greenish in colour. The criteria for a *G. abietina* canker are:

1. Yellow-greenish colour of the infection area.
2. Time of infection; by checking, whether the canker formation starts near the pith of the branch. Cankers which are formed one year or more after the shoot formation are excluded.
3. Cankers are most often formed in the whorl between two internodes.
4. Canker shape is somewhat typical to *G. abietina* infection: The bark has the appearance of having exploded; quite often the bark is still intact in the middle of the canker.

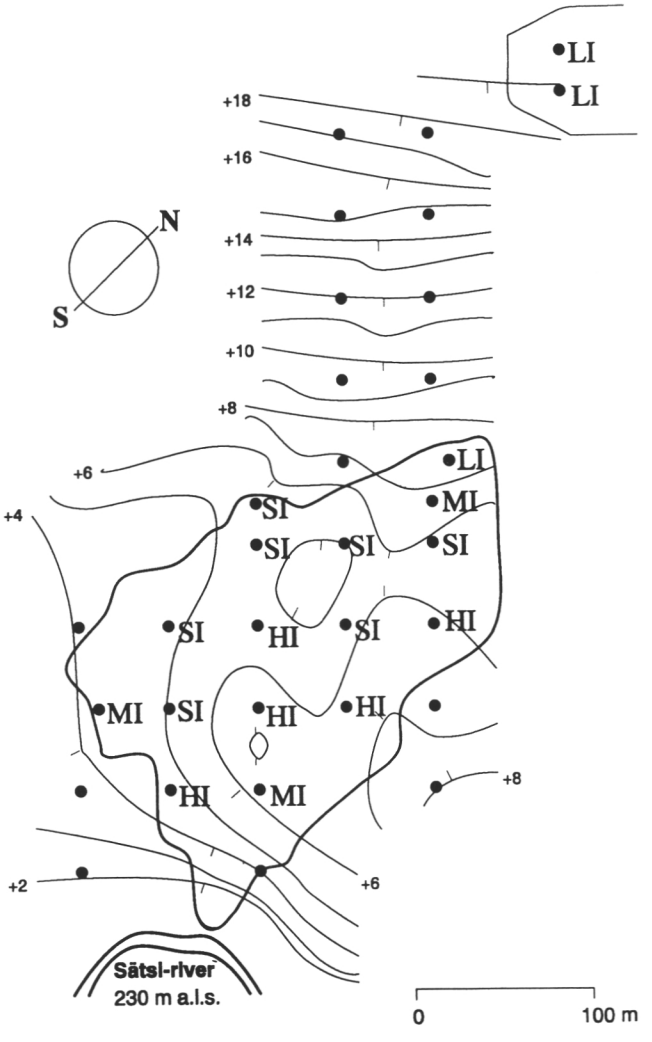

Figure 1. The sample plots and the damage class (according to Hopkins *et al.* 1979) in each sample plot in the Rikkilehto stand.

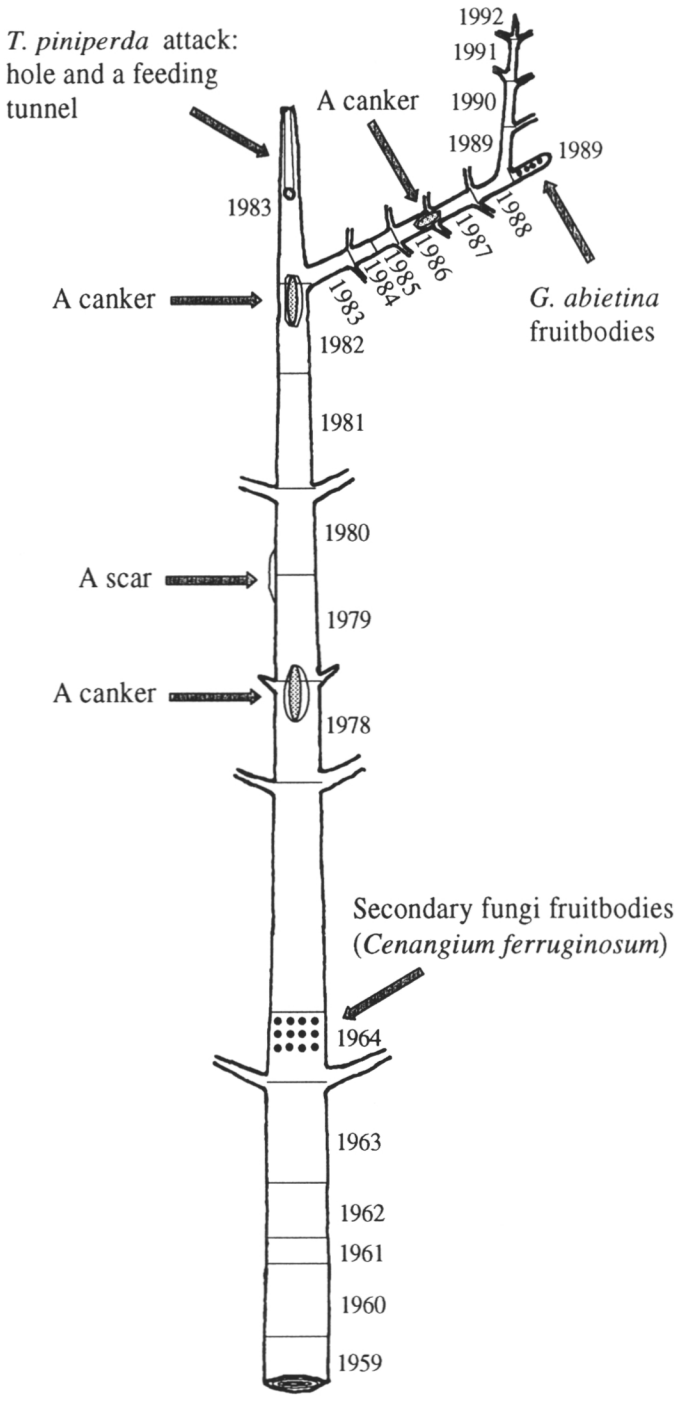

Figure 2. A schematic picture showing an example of the branch analysis.

Leader changes were judged to have been caused by *G. abietina*, unless symptoms of *Tomicus* spp. attacks were found. The year of death of whole branches were counted from the cross section of the branch base or from the branch whorls. The year of *Tomicus* attacks were determined by the following procedure:

1. If the attack had occurred in the current year shoot or in an older shoot, and the shoot was still on the branch, the year of the attack was the same as the birth year of the youngest shoot.
2. If the attacked shoot had fallen down, and there was only the basal part of the feeding tunnel left at the tip of the branch, the year of the attack was the birth year of the attacked shoot as determined from side branches + the number of tree rings counted from the cross section under the point of attack –1.

Results

In the damaged area, 59.1 % of the pines were dead and 9.3 % were assumed to be dying. Only 3.6 % of the pines were not infected by *G. abietina*. In the relatively healthy area, 18.1 % of the pines were dead and 6.0 % were assumed to die shortly. All the dead trees belonged to the non-dominating tree classes. The close spacing of this stand had been the main reason for the damage (Table 1). According to Hopkins *et al.* (1979), 43 % of the plots were severely infected, 36 % highly infected, 14 % medium infected and 7 % slightly infected. In the relatively healthy area, both plots were slightly infected.

The damage class determined according to Hopkins *et al.* (1979) correlated negatively with the elevation of the plot and positively with the pH value of the humus layer (Table 2). The damage was most severe in the lowest part of the area. The other variables did not correlate with the degree of damage. The damage classifications correlated significantly with each other.

Other injuring agents were found, too. About 15 % of the pines were infected by *Lachnellula pini* (Brunch.) Dennis. The most important insect was *Tomicus piniperda* L. and its attacks in young shoots.

Of the fourteen trees used in the branch analysis, the average breast height diameter was 7.7 cm, average height was 8.3 m and the damage class according to Uotila's (1985) classification ranged between 40 and 95 %. According to branch analysis the number of scars increased as of 1979 and was at its highest level during the period 1981–1988. The number of cankers increased dramatically in the 1980's. The highest number of cankers occurred during the period 1982–1986. The number of cankers decreased steeply as of 1987. The highest number of leader changes occurred during the period 1983–1989. The *Tomicus* attacks increased as of 1980. The first peak occurred during the period 1983–1985 and the second one in 1988–1989. The number of attacks was relatively high in 1990, too.

Table 1. The trees in the sample plots in each damage class.

Damage class	Damage area (%)	Healthy area (%)
Healthy (0–20 %)	3.6	33.9
Moderately damaged (21–65 %)	28.0	42.0
Dying (65–99 %)	9.3	6.0
Dead (100 %)	59.1	18.1

Table 2. The Spearmann's correlation coefficient between the damage class and certain plot variables.

Variables	Stand elevat.	Humus depth	A hor. depth	pH humus	[1]Sps A horiz.	*P.sylv.* /ha	*P.abies* /ha	*B. pub.* /ha	Uotila damage
HOP	–0.541*	–0.098	0.427	0.520	–0.317	–0.327	–0.284	0.084	0.914***

[1]Small particle size in the A horizon

Branches have died regularly since the closing of the canopy in the mid-1950's. In the early 1980's a large number of branches died with the peak occurring in 1984.

Radial increment had started to decrease since the mid-1970's, continued to do so into the 1980's, and did not recover in the late 1980's. The number of infections was not found to correlate with radial increment.

The variations in the epidemics based on the number of scars and cankers can be seen in different parts of the canopy (Fig. 3). About 20–47 % of the youngest shoots in the uppermost four whorls were infected during the period 1980–1984. This was 5–10 % more than in the mid canopy and 12–35 % more than in the lower canopy. The situation remained the same in the late 1980's.

The peaks of the *Tomicus* attacks were in all parts of the canopy. In 1984, 9 % of the youngest shoots in the four uppermost whorls, 2 % in the middle part and 0 % of the lowest part were attacked. In 1988–1989, the number of attacks was 13.5–16.5 % in the upper canopy and 4.0–5.0 % in the lower canopy. The number of attacks was still high (7.0 %) in the upper canopy in 1990.

The number of cankers and scars do not correlate very well with the monthly rainfall during the growing season (Fig. 4). The summer of 1981 was exceptionally rainy (June–August), but the peak of the epidemic occurred three years later in this stand. However, plantations had severe damage in 1982 in northern Finland (Jalkanen 1984).

The amount of SO_2 in rain water measured in Naruska 1989–1991 in 10 days intervals has rarely exceeded 4 $\mu g/m^3$ air, which is considered to be the normal background dose in the air in Finland (see Huttunen *et al.* 1992).

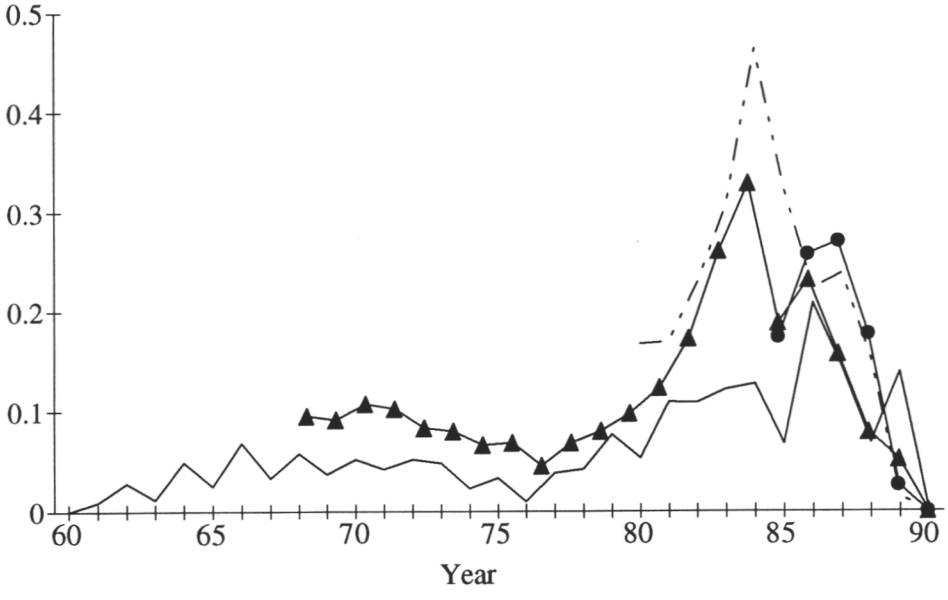

Figure 3. The number of scars and cankers in different parts of the canopy during different periods: 1985–1990 (dot), 1980–1984 (- · · -), 1969–1979 (triangle), and 1938–1968 (——).

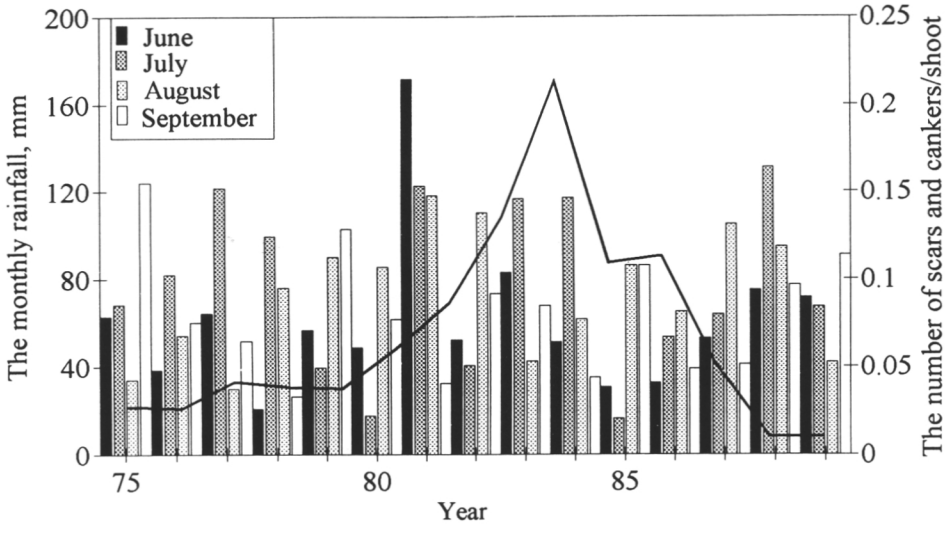

Figure 4. The number of scars and cankers per shoot (solid line) in relation to the monthly rainfall during the growing period (columns).

Discussion

According to branch analysis, *G. abietina* has been present in the studied forest for several decades. Small peaks have occurred approximately at the same time as the epidemics previously observed in other parts of Finnish Lapland. Since early 1980's, the epidemic has strengthened probably because of the cold summer of 1981.

The weakening of the epidemic in eastern Lapland has been reported on a general level (Salemaa *et al.* 1991). High numbers of leader changes occurred at the same time as the epidemics. Because of this, it is impossible for *G. abietina* to have killed shoots without leaving any marks on the shoots. The number of *Tomicus* attacks has increased during the same period as the epidemic. The peak in the late 1980's is obviously a consequence of the increasing number of dead trees suitable for beetles to multiply in after the peak of the epidemic. The high number of dead branches for the period 1983–1986 also supports this. The epidemic eased off in the late 1980's, but the recovery of the trees is not yet visible in terms of improved radial increment (Kaitera & Jalkanen 1993a). It is obvious that the successful *G. abietina* infections have affected to the retardation of radial growth. *Tomicus* attacks have probably had a minor effect on the reduction in radial increment.

The higher infection level in the upper canopy as compared to the lower part can be explained by the high number of vigorous but susceptible shoots, the greater length of the shoots or by the different moisture conditions within the canopy. The infection differences can be explained if all the shoots in the canopy have had the same chance to get infected because of high level of inoculum. The peaks of the epidemic can be seen in all parts of the canopy. *Tomicus* attacks occurred more often in the upper canopy than the lower. This has been noticed in earlier studies (Salonen 1973, Långström 1980).

Branch analysis as a method is most useful in a forest where the trees have recovered after an epidemic. It is also supposed that latent infection and the infection into older shoots are rare or these kinds of infections cannot produce cankers resembling those of *G. abietina*. Even if this does occur, the error in the infection year estimation cannot be very high. The differences between years in infection can still be detected well enough.

One weakness of the method is that scars are not very reliable variables in the oldest branches. The method should be used only in the living part of the canopy. If the epidemic has been so strong that most of the branches have died during the epidemic, the method will not provide accurate information about the following epidemics. The method of determining *Tomicus* outbreaks is most useful in young stands and when the attacked shoots are still intact on the branches. However, wind-thrown forests are potential places for using this method.

Most of the damaged sites in eastern Lapland are in stands of first-thinning age (Kaitera & Jalkanen 1991). The study area also belongs to this category. The disease incidence correlates well with sample plot height. The worst damage is located near the river at the base of the slopes in valleys. In southern Finland, the damage is concentrated on the one kind of sites (Aalto-Kallonen & Kurkela 1985, Sairanen 1990). Soil properties and the spacing of trees did not correlate with the disease incidence. The effect of tree spacing is very difficult to estimate because the fungus has been killing trees for several years. If we assume that both areas receive the same amount of deposition, it is probably not the deposition that is the major cause of the damage. However, it is very difficult to estimate the effects of pollution on the basis of only the Rikkilehto stand. The effect of small SO_2 peaks is not known.

It is probable that the very rainy summer of 1981 weakened the trees and made them susceptible to further infections during the following three seasons. The partly rainy summers of 1983–1984 were very good for the fruitbodies to mature; this can be seen in the heavy infection levels. The lack of spores may have been the main cause of the low infection level in 1981. It is obvious that the effect of a extraordinary wet summer has lasted for several growing periods in the damage area and the number of spores in the air has been the major factor affecting the epidemics.

The role of *L. pini* in the damage process is not known. It was obvious, that the fungus has lived in the stems for several decades. Therefore, it may have a minor role in the damage process.

References

Aalto-Kallonen, T. & Kurkela, T. 1985. Gremmeniella disease and site factors affecting the condition and growth of Scots pine. Communicationes Instituti Forestalis Fenniae 126. 28 p.

Hopkins, D. F., Abrahamson, L. P. & Johnson, W. L. 1979. Detection and classification of Scleroderris canker in pine stands using aerial photography. Syracuse, New York, USA; College of Environmental Science and Forestry, State University of New York. 71 p.

Huttunen, S., Tikkinen, S., Bäck, J., Lamppu, J. & Manninen, S. 1992. Ilman rikkipitoisuudet, puiden vaurio-oireet ja luppojen rikkikertymät. Abstract: Sulphur dioxide concentrations in the air, tree injury symptoms and sulphur accumulation in needles and Bryoria species. In: Kauhanen, H. & Varmola, M. (eds.). The Lapland Forest Damage Project. Interim Report. Metsäntutkimuslaitoksen tiedonantoja 413: 136–141.

Jalkanen, R. 1984. Die-backs of Scots pine due to unfavourable climate in Lapland. Aquilo Series Botanica 23: 75–79.

— 1987. Gremmeniella har härjat i hundra år. Skogs-eko 1987(8). 12 p.

— & Kaitera, J. 1992. Versosurma Itä-Lapissa. Abstract: Damage caused by Gremmeniella abietina in Eastern Lapland. In: Kauhanen, H. & Varmola, M. (eds.). The Lapland Damage Project. Interim Report. Metsäntutkimuslaitoksen tiedonantoja 413: 215–226.

Kaitera, J. & Jalkanen, R. 1991. Versosurman (Ascocalyx abietina (Lagerb.) Schläpfer-Bernhard vaivaamat alueet metsähallituksen Ylikemin hoitoalueessa Koillis-Suomessa. Metsäntutkimuslaitos, Rovaniemen tutkimusasema. Moniste. 12 p.
— 1992. Disease history of Gremmeniella abietina in a Pinus sylvestris stand. European Journal of Forest Pathology 22: 371–378.
— 1993a. Surmakka (Gremmeniella abietina (Lagerb.) Morelet) Sallan Naruskan Rikkilehdossa. Manuscript.
— 1993b. The history of shoot damage by Tomicus spp. (Col. Scolytidae) in a Pinus sylvestris L. stand damaged by Gremmeniella abietina (Lagerb.) Morelet. Journal of applied Entomology (submitted).
Kangas, E. 1937. Tutkimuksia mäntytaimistotuholaisista ja niiden merkityksestä. Referat: Untersuchungen über die in Kiefernpflanzbestände auftretenden Schäden und ihre Bedeutung. Communicationes Instituti Forestalis Fenniae 24. 304 p.
Kujala, V. 1950. Über die Kleinpilze der Koniferen in Finnland. Communicationes Instituti Forestalis Fenniae 38. 121 p.
Kurkela, T. 1967. Keväällä havaitusta männyn taimitarhataudista ja Scleroderris lagerbergiista. Summary: On a nursery disease of Scots pine observed in the spring of 1967 and the fungus Scleroderris lagerbergii. Metsätaloudellinen Aikakauslehti 1967(12): 391–392.
— 1981. Versosyöpä (Gremmeniella abietina) riukuasteen männiköissä. Summary: Canker and dieback of Scots pine at precommercial stage caused by Gremmeniella abietina. Folia Forestalia 485. 12 p.
Långström, B. 1980. Distribution of pine shoot beetle attacks within the crown of Scots pine. Studia Forestalia Suecica 154. 25 p.
Norokorpi, Y. 1971. Männyn viljelytaimistojen tuhot Pohjois-Suomessa. Metsä ja Puu 1971(4): 23–26.
— 1972. Pohjoisten männyn viljelytaimistojen tuhoprosessista. Metsä ja Puu 1972(4): 13–15.
Salemaa, M., Jukola-Sulonen, E-L. & Lindgren, M. 1991. Forest condition in Finland, 1986–1990. Seloste: Suomen metsien elinvoimaisuus vuosina 1986–1990. Silva Fennica 25(3): 147–175.
Sairanen, A. 1990. Site characteristics of Scots pine stands infected by Gremmeniella abietina in Central Finland. I: Mineral soil sites. Seloste: Versosurman vaivaamien männiköitten kasvupaikkaominaisuudet Keski-Suomessa. I: Kivennäismaat. Acta Forestalia Fennica 216. 27 p.
Salonen, K. 1973. On the life cycle, especially on the reproduction biology of Blastophagus piniperda L. (Col., Scolytidae). Seloste: Pystynävertäjän (Blastophagus piniperda L., Col., Scolytidae) elämänkierrosta, erityisesti sen lisääntymisbiologiasta. Acta Forestalia Fennica 127. 72 p.
Uotila, A. 1985. Siemenen siirron vaikutuksesta männyn versosyöpäalttiuteen Etelä- ja Keski-Suomessa. Summary: On the effect of seed transfer on the susceptibility of Scots pine to Ascocalyx abietina in southern and central Finland. Folia Forestalia 639. 12 p.

Respiration of *Phacidium infestans* in winter

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Abstract

The aim of this research was to determine the *in situ* activity of *Phacidium infestans* Karst., snow blight of pine over the winter by measuring the quantity of carbon dioxide released from infected needles at different temperature and illumination conditions without disturbing the snow cover. The material used was two kilograms of fresh branches which were placed in heaps about one meter from each other. The CO_2 measurements with an infrared gas analyser were conducted in 1–2 days a week and were repeated at least five times on each measurement day during the whole winter as long as the branches were under the snow cover. The experiments were done during two winters, 1983–1984 and 1984–1985. To cause infection the heaps were inoculated with needles infected during the previous winter. To prevent fungal growth in the control heaps, the branches were treated with a fungicide (kvintotzen, PCNB). The temperature in air and under the snow as well as the snow depth were measured. The respiration of snow blight depended mainly on the temperature under the snow and was highest during late winter. CO_2 concentration correlated under the snow positively and significantly with the temperature. CO_2 concentration correlated also positively with time. Therefore, CO_2 concentration was highest when the temperature was highest ie. during late winter. The role of soil respiration was discussed.

Production and release of ascospores by *Phacidium infestans*, a snow blight fungus on Scots pine

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Abstract

Production of ascospores of the fungus, *Phacidium infestans* Karst. was monitored with spore traps during two autumn periods. Different meteorological factors were also recorded and their effects on spore release investigated.

Introduction

Apothecia of *Phacidium infestans* Karst. develop in autumn, and ascospores are released and dispersed until winter snow cover is laid (e.g. Björkman 1948, Roll-Hansen 1989). Detailed investigations of the production and release of the spores of this fungus have not been made. In Canada, Smerlis (1968) collected ascospore samples from *Pacidium abietis* (Dearn.) Reid & Cain and *Lophophacidium hyperboreum* Lagerb., both of which are snow blight fungi on conifers. With the method used, he could only record the period of spore production, and not the effects of weather conditions on spore release. The spore production period for snow blight fungi in northern Europe may be similar to that in Canada.

Many ascomycetes discharge their spores only after rain has wet the ascocarps. This is a striking and consistent feature of the epidemiology of all the major plant diseases caused by ascomycetes (Ingold 1966). Mature asci in the wet ascocarps of *Rhytismataceae* fungi have been observed to protrude above the general surface of the hymenium and to discharge spores violently (Minter & Cannon 1984). Hyaline ascospores, like those of *P. infestans*, often occur in the atmosphere most abundant during the night (Gregory 1973). One reason for that might be high relative humidity and night dew which provides enough moisture for spore liberation. Spore release from the ascocarps of ascomycetes has been investigated in several ascomycetes pathogenic on forest trees or cultivated plants. Ascocarps which have greater stroma around hymenial tissue, such as those in the genus *Hypoxylon*, or which are immersed in a mass of host tissue, often have a diurnal pattern in their rate of spore liberation (De Groot 1968, Hodgkiss &

Harvey 1969, Kramer & Pady 1970). Spore liberation from erumpent ascocarps or those immersed in only tiny pieces of host tissue, tends to depend very cosely on rainfall (Skilling 1969, Ramsdell *et al.* 1974, Perrin 1978, Laflamme & Archambault 1990). In particular, ascospore liberation in *P. infestans* may follow the same pattern observed in some needle cast fungi (Lanier & Sylvestre 1971, Osorio & Stephan 1991).

In this study, ascospore production by *Phacidium infestans* was monitored by spore trapping. The relationship between various meteorological factors and ascopore release was also investigated.

Material and methods

The material was collected during two years, 1971 and 1974. Excised Scots pine (*Pinus sylvestris* L.) branches infected by *P. infestans* during the previous winter were used as the ascospore source. The branches were collected in Leivonmäki, Central Finland. In 1971, spore trapping was conducted at the forest site in Tuusula; the spore dispersal of *Melampsora populnea* (Pers.) Karst. was also studied at the same site during the same year (Kurkela 1973). In 1974 spore trapping was made in a garden in Suutarila, a suburb of Helsinki. The branches were exposed to outside weather conditions throughout the entire trapping period. Temperature, relative humidity, and wind velocity were recorded from the beginning to the end of the trapping periods. Observations of diurnal dew periods were made with a dew balance (Huovila 1968). Precipitation was first recorded with a pluviometer until the onset of frequent night frosts. All meteorological factors were recorded (see Kurkela 1973). After the onset of night frosts, duration of precipitation was recorded with dew balance in which the gauge was adjusted so that rain water could flow slowly through the bottom. The amount of dew per night in Finland is usually less than 0.1 mm (Huovila 1968), which was more or less the lowest amount of precipitation which could be measured by the pluviometer. Precipitation always caused a sudden increase in the dew balance recordings, while dew accumulated very slowly.

In 1971, spore trapping was made with volumetric spore traps; the tape used in the trap was handled in the same way as described previously (Kurkela 1973). The spore source, the excised branches, were put hung on the trap just in the front of the orifice. Thus the flight of spores was always toward the trap orifice despite of the wind direction.

In 1974, spores were trapped with a volumetric trap which makes discrete spore prints, three mm apart on the edge of an acrylic disk with a diameter of 185 mm. The width of the trapping surface at the disk egde was 20 mm. The orifice was wedge-shaped, narrowing toward the trapping surface, where it was 0.5×14 mm. The trap did not rotate but the orifice was directed downwards to prevent the entering of rain

water. The excised branches were evenly distributed around the orifice. The suction time intervals for each spore print was controlled with an electric timer, and varied from circa three minutes to 24 hours. The shortest adjustable time possible using riders on the edge of the timer disk was 2.5 minutes. For example, if a time interval of 30 minutes was used, 2.5 minutes were required for the four mm movement of the drum, and during the remaining time the duration of suction could be adjusted from three to 27.5 minutes. The latter time setting was used during the trapping period in 1974. Thus, the amount of spores was recorded every half hour.

Spores impinged on the vaseline coated trapping surface. The spores were removed from the drum using 19 mm Scotch Magic tape. The tape was then cut into pieces and mounted e.g. in gelatine glycerine (Kaiser's) on a standard objective slide, glued side up. A more detailed description of this trap has been published elsewhere (Kurkela 1993).

Spore data for each recording time was obtained by surveying five microscopic fields across the tape (for both spore traps). A magnification of 10 × 20 was used. Although both traps provided volumetric recordings, only the actual counted numbers are presented in this paper. The condition of the ascocarps was checked before the continuous recording, and at the end of recording during a two week period. Spore trapping was begun when microscopic slides revealed that some spores had been released from the asci. Trapping was terminated in 1971 when snow covered the branches, and in 1974 when ascocarps contained only empty asci. Only part of the material is presented and no statistical treatment has been made.

Results

Spore production of *P. infestans* begun in September in both years. In 1971, the first real burst of spores occurred on the 12th of September (Fig. 1). Some single spores had already been detected earlier, but they might represent some other fungi. In 1974, the first spores were recorded on the 23rd of September (Fig. 2). Because the spore trapping was conducted in 1974 at a managed garden area, obviously there was no background load of other spores, similar to those of *P. infestans.*

In 1971, ascospores were trapped until the establishment of persistent snow cover on the 18th of November. In 1974, the temperature remained at an exceptionally high level until the end of the year. The last spores were trapped on the 14th of December. Trapping was continued until the 21st of December. At that time, the microscopic survey revealed the total exhaustion of the spore production capacity of the ascocarps on the experimental branches. Only empty asci could be found, from which spores had been released naturally.

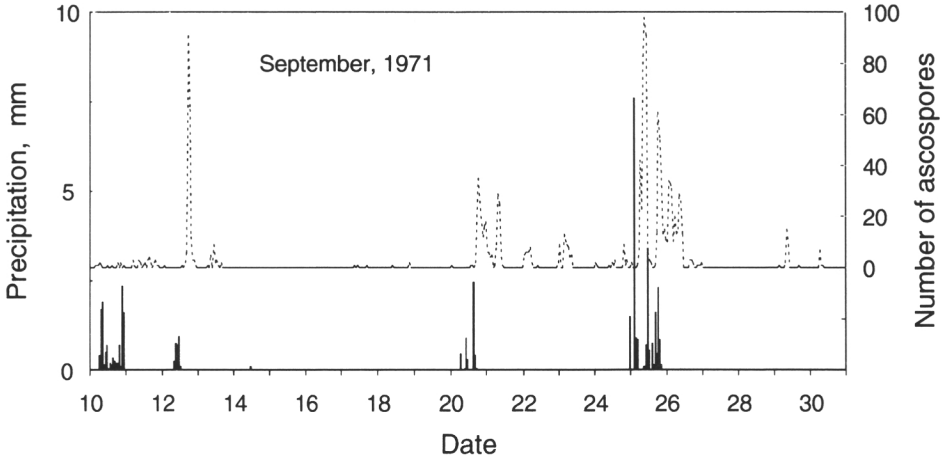

Figure 1. Number of ascospores trapped, and precipitation in mm, in September 1971.

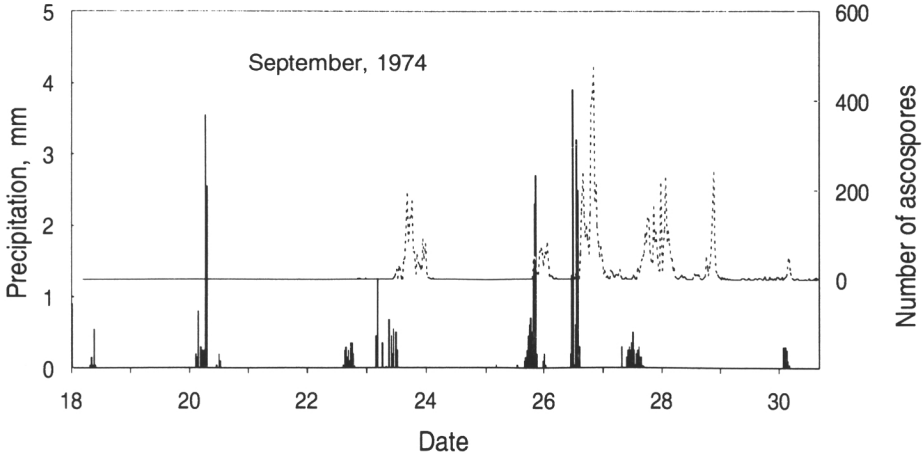

Figure 2. Number of ascospores trapped, and precipitation in mm, in September 1974.

In both years the highest one hour spore counts were obtained in October. Spore release continued at a relatively high level also in November. For December, data was collected only in 1974. Spore yields obtained in December were similar to those obtained in the beginning of the spore release period in September (Table 1).

The maximum number of spores trapped during one hour was 1671 and over 17 000, in 1971 and 1974, respectively. The difference in numbers between these two years has most probably caused by the differences in the branch material and the closer location of the spore source to the trap orifice in 1974.

Table 1. Maximum spore yield for each half month period, given as percentages of the highest yield, recorded during the second half of October.

Date		1971	1974
September,	1–15	5	–
	16–30	6	5
October,	1–15	40	96
	16–31	100	100
November,	1–15	45	55
	16–30	23	7
December,	1–13	–	1

The release of ascospores was closely associated with the occurrence of free water on the needles. The release of spores began approximately four hours after the start of rainfall. Usually the spore release reached its maximum in 6 to 9 hours after the beginning of the rain. If the rain was not repeated, the number of spores declined gradually to zero. With repeated rainfalls or if relative humidity remained at a high level (> 90 %), or if precipitation was followed by a dew period, a spore release period could continue for even more than two days. Sometimes spore release was initiated without rain, after the melting of rime on the needles when the temperature rose above 0 °C. Otherwise the number of spores during the release period did not depend on the actual temperature. However, temperature may induce the maturing of ascospores in apothecia during the rainless time preceding rainfall and the initiation of spore release.

Discussion

Snow blight on Scots pine is rare or non-existent on the southern coast and in the greater part of the western coast of Finland. The main reason for that seems to be the lack of a persistent snow cover in those areas during the winters. In some places, the length of the snow period may not be a limiting factor for the spreading of *P. infestans*, but a very late onset of persistent snow cover may not allow the fungus to complete the infection process on the needles. Ascospores can germinate on the needles during wet weather, but obviously they are not able to penetrate the needle tissue. Neither can the mycelium of the fungus grow between needles without a persistent snow cover.

References

Björkman, E. 1948. Studier över snöskyttesvampens (Phacidium infestans Karst.) biologi samt metoder för snöskyttets bekämpande. Meddelande från Statens Skogsforskningsinstitut 37(2). 136 p.

De Groot, R.C. 1968. Diurnal cycles of airborne spores produced by forest fungi. Phytopathology 58: 1223–1229.
Gregory, P.H. 1973. Microbiology of the atmosphere. 2nd ed., Leonard Hill. 377 p.
Hodgkiss, I.J. & Harvey, R. 1969. Spore discharge rhytms in Pyrenomycetes. VI. The effect of climatic factors on seasonal and diurnal periodicities. Transactions of the British Mycological Society 52: 355–363.
Huovila, S. 1968. On the amount of dew in Finland. Geofysica 10: 75–80.
Ingold, C.T. 1966. Aspects of spore liberation: violent discharge. In: Madelin, M.F. (ed.). The Fungus Spore. Butterworths. Colston Papers 18: 113–132.
Kramer, C.L. & Pady, S.M. 1970. Ascospore discharge in Hypoxylon. Mycologia 62: 1170–1186.
Kurkela, T. 1973. Epiphytology of Melampsora rusts of Scots pine (Pinus sylvestris L.) and aspen (Populus tremula L.). Communicationes Instituti Forestalis Fenniae 79(4). 68 p.
— 1993. A sampler for spore release studies making discrete spore prints. Karstenia (submitted).
Laflamme, G. & Archambault, L. 1990. Evaluation of microclimatic factors affecting ascospore release of Gremmeniella abietina var. balsamea. Canadian Journal of Plant Pathology 12: 190–194.
Lanier, L. & Sylvestre, G. 1971. Epidémiologie du Lophodermium pinastri (Schrad.) Chev. Résultats de quatre années d'études à l'aide d'un piège à spores de Hirst. European Journal of Forest Pathology 1: 50–63.
Minter, D.W. & Cannon, P.F. 1984. Ascospore discharge in some members of the Rhytismataceae. Transactions of the British Mycological Society 83: 65–92.
Osorio, M. & Stephan, B.R. 1991. Life cycle of Lophodermium piceae in Norway spruce needles. European Journal of Forest Pathology 21: 152–163.
Perrin, R. 1978. Etude de la sporulation de Nectria ditissima Tul. Agent du chancre du hêtre. Annales des Sciences Forestières 35: 213–228.
Ramsdell, D.C., Nelson, J.W. & Myers, R. 1974. An epidemiological study of mummy berry disease of highbush blueberry. Phytopathology 64: 222–228.
Roll-Hansen, F. 1989. Phacidium infestans. A literature review. European Journal of Forest Pathology 19: 237–250.
Skilling, D.D. 1969. Spore dispersal by Scleroderris lagerbergii under nursery and plantation conditions. Plant Disease Reporter 53: 291–295.
Smerlis, E. 1968. Ascospore discharge of Lophophacidium hyperboreum and Phacidium abietis. Bi-Monthly Research Notes 24. 42 p.

Needle fungi of Norway spruce

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Abstract

A few fungal species inhabiting needles of Norway spruce (*Picea abies* (L.) H. Karst.) are described: the epiphytic living *Rhizosphaera kalkhoffii* Bubak, the two endophytes *Tiarosporella parca* (Berk. et Br.) Whitney *et al.*, and *Lophodermium piceae* (Fuckel) v. Höhnel, and the needle pathogen *Lophodermium macrosporum* (Hartig) Rehm. Detailed descriptions are given particularly on morphological characters, variation and life cycle of *Lophodermium piceae*.

Introduction

The needles of Norway spruce (*Picea abies* (L.) H. Karst.) are inhabited frequently by many microfungi (Rack & Butin 1984, Butin 1986, Mack 1989). In connection with the forest decline in central Europe and here particularly with the reddening of spruce needles, some needle fungi were considered as pathogens causing the symptoms. Some needle fungi are indeed true parasites. Others are living saprophytically on dying or dead needle tissue. A third group has been shown to live endophytically in the green needle tissue without causing any symptoms for a more or less long period. If the needles become senescent by age or other reasons, e.g. effect of air pollution, these endophytes finish their life cycles and produce fruitbodies. To differentiate clearly between the various types of needle inhabiting fungi it is necessary to study the biology of these organisms thoroughly and to determine their life cycles. In course of identification studies of microfungi in and on Norway spruce needles one will find many species, of which the life cycles are not yet known. In the present paper four more frequent spruce needle fungi are described. These fungal species occur also on spruce in Scandinavia (e.g. Solheim 1988, 1989, Livsey & Barklund 1992).

Tiarosporella parca (Berk. et Br.) Whitney, Reid et Pirozynski
(Fig. 1a)

This coelomycetous fungus can be found on brown shed or still attached needles during autumn and particularly in winter. The round

and black pycnidia are often difficult to distinguish and can easily be mistaken for the anamorph stage of *Lophodermium piceae* (Fuckel) v. Höhnel. The pycnidia of *T. parca* measure 160 to 300 µm, open up with a slit and release one-celled, cylindrical, 42 × 6–8 µm measuring pycnospores with a characteristic apical mucilaginous appendage (Whitney *et al.* 1975).

The biology and life cycle of *T. parca* is not yet well understood. The fungus is found in brown needles, but can also be isolated from green, symptomless needles (Heiniger & Schmid 1989, Rack & Butin 1984, Butin 1986). It can obviously be considered as an endophyte. *T. parca* seems to be associated with the ascomycete *Darkera parca* Whitney *et al.* However, the connection is still speculative and not yet proved by cultural studies. In Europe the teleomorphous stage was found only once in Czechoslovakia in the year 1932. In Canada (Alberta) this stage is found on needles of *Picea glauca* (Moench.) Voss (Whitney *et al.* 1975).

T. parca may have been overlooked in the past. The natural distribution can therefore not yet be explained in detail. Until now the fungus has been observed mainly in the alpine regions (Switzerland, Austria, Southern Germany) and in Scandinavia (Norway, Sweden, Finland). It might be a psychrophilic fungus, as it grows with an optimum at +15 °C (Heiniger & Schmid 1989), and occurs naturally in cooler regions.

***Rhizosphaera kalkhoffii* Bubak** (Fig. 1b)

This coelomycete is distributed worldwide and lives mainly on spruce needles. On brown needles of Norway spruce the fungus is very frequent and can easily be recognized by its roundish, black pycnidia which protrude through the stomata. Their size is 50–95 × 115 µm. The pycnidia contain one-celled, hyaline conidia of 5–10 × 3.5 µm.

Infection trials have shown that *R. kalkhoffii* is obviously an epiphyte which colonizes very rapidly dying or dead needles (Dotzler 1989). Then, the fungus can finish its life cycle within a few weeks by the production of fruitbodies. Although *R. kalkhoffii* is a very common fungus on spruce needles, it occurs mostly separate from other needle fungi and not in mixture (Stephan & Osorio 1993).

***Lophodermium macrosporum* (Hartig) Rehm** (Fig. 1c)

This ascomycete is obviously less common than its close relative *Lophodermium piceae*. But in some years this fungus causes severe needle damage on young shadowed spruce trees in dense stands. Single needles change colour from green to light brown in spring and die. It is very typical that green and dead needles are mixed in even-aged shoots. After the development of conidiomata of the anamorphous

stage *Hypodermina hartigii* Hilitzer during summer and autumn the very long (2 to 8 mm) hysterothecia of *L. macrosporum* are produced on the undersurface of the infected dead, then 2-year-old needles. At maturity the ascomata open with a slit and release the filiform-cylindrical, aseptate, hyaline ascospores. More details on the morphology were given by Cannon & Minter (1984).

The infection of a needle by *L. macrosporum* can be identified easily by the typical black ring at the needle base. The abscission mechanism is disturbed by the deposition of phenolic compounds. Therefore, infected needles are not shed, remain attached to the shoot even after dying of the needle, and are normally not found in the litter.

The life cycle of *L. macrosporum* can last 2 to 3 years. The fungus can be considered as a real needle pathogen on various spruce species. There is little information on the variation of *L. macrosporum*, although differences were found between samples from various geographical regions (Osorio & Stephan, unpublished data).

The species is widespread in central and northern Europe and in some areas of North America. However, it is not clear whether the natural distribution depends on special climatic conditions. In large areas with Norway spruce stands the fungus cannot be found, e.g. in northern Germany.

***Lophodermium piceae* (Fuckel) v. Höhnel** (Fig. 1d)

This ascomycete is the most common needle fungus of Norway spruce, and scientifically known since nearly 200 years (Osorio & Stephan 1990). The presence of *L. piceae* can be recognized by its anamorphous and/or teleomorphous stages, and in most cases also by black zone lines on needles in the litter or still attached to the tree. Detailed descriptions of the fruitbodies as well as of the conidia and ascospores are given elsewhere (Osorio & Stephan 1991b). For the various morphological characters the following average values have been calculated: ascomata 1,171 × 544 µm, asci 137 × 12 µm, ascospores 98 x 3 µm, paraphyses 130 × 2 µm, conidiomata 282 × 201 µm, conidiogenous cells 14 × 2.5 µm, conidia 5 × 1.8 µm.

The life cycle of *L. piceae* can be described briefly in the following way (Osorio & Stephan 1991a): The spruce needles are infected by ascospores in spring during flushing (Fig. 2, I). It is obvious that the ascospore produces an appressorium on the needle surface (Osorio & Stephan 1989) and penetrates the cuticula directly by an infection tube. After infection the fungus can live for some time, probably for several years, in the green needles without causing symptoms (Fig. 2, II). This has been proved by isolating *L. piceae* from green symptomless spruce needles. Therefore, *L. piceae* must be considered as an endophyte which completes its development, when the needle starts dying for several reasons (effect by abiotic or biotic factors, ageing etc.).

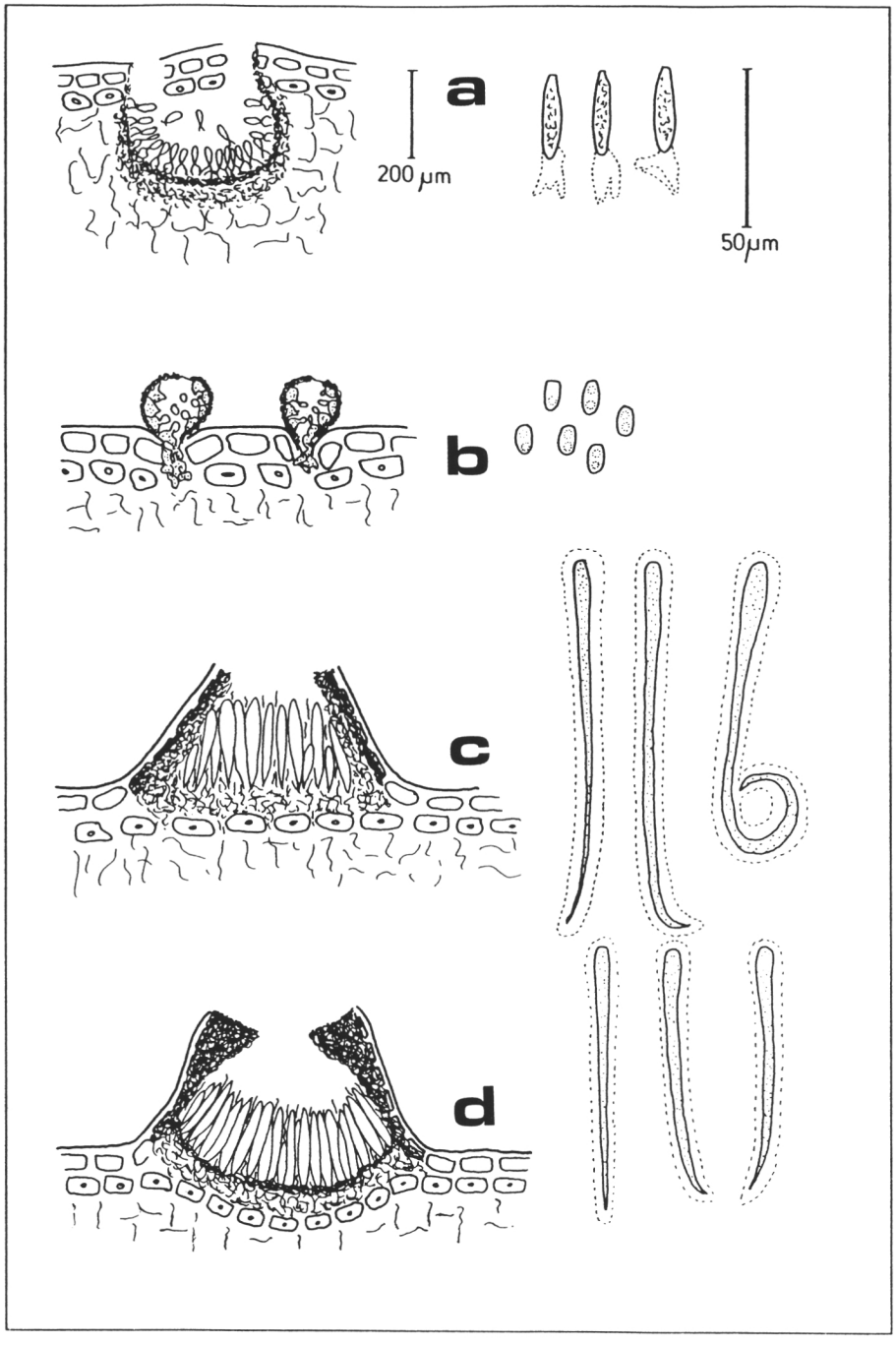

Figure 1. Fungal species inhabiting Norway spruce needles. a = *Tiarosporella parca*: pycnidium in vertical transection (left) and conidia (right). b = *Rhizosphaera kalkhoffii*: pycnidium in vertical transection (left) and conidia (right). c = *Lophodermium macrosporum*: hysterothecium in vertical transection (left) and ascospores (right). d = *Lophodermium piceae*: hysterothecium in vertical transection (left) and ascospores (right).

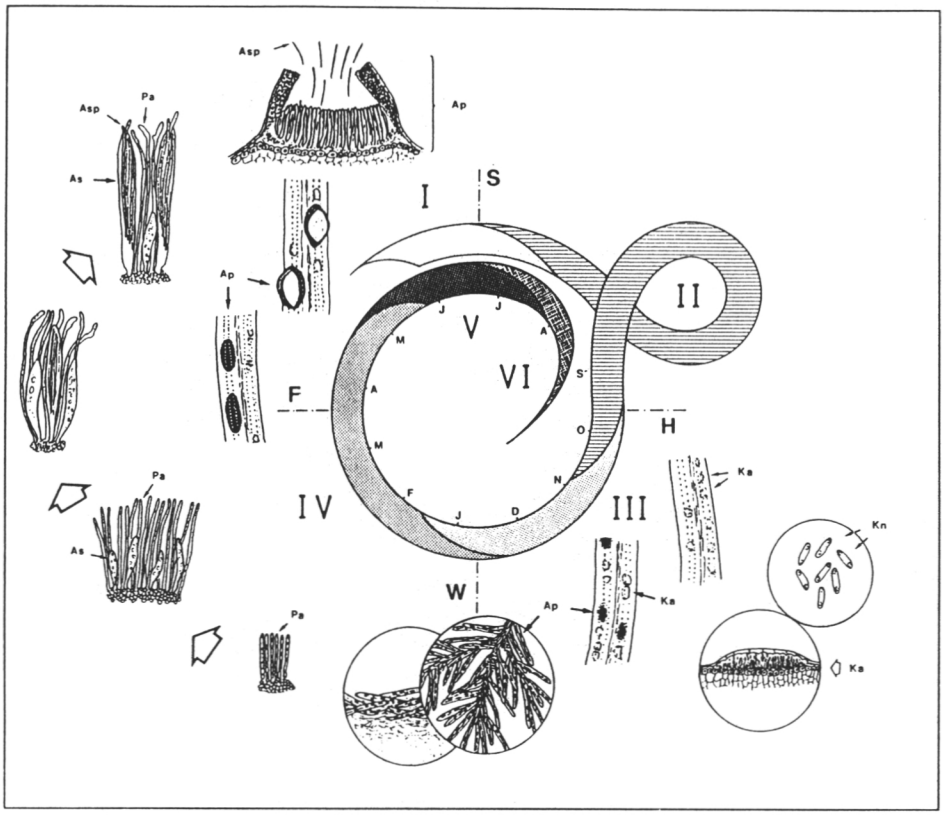

Figure 2. Life cycle of *Lophodermium piceae* on Norway spruce. I = inoculation of current year needles, II = endophytism for several years, in exception for one year, III = formation, development and maturity of conidiomata, IV = formation and development of ascomata, V = maturity of ascomata and ascospore release, VI = deterioration of ascomata and needles in the litter. Abbreviations: Ap = ascoma, As = ascus, Asp = ascospore, Ka = conidiomata, Kn = conidia, Pa = paraphyses; seasons: F = spring, S = summer, W = winter (From Osorio & Stephan 1991a).

At this stage the conidiomata and conidia are formed, mainly at the end of summer and the beginning of autumn (Fig. 2, III). The anamorph matures between the end of October and the beginning of December. Formation and ripening of ascomata occur between January and April (Fig. 2, IV). Mature ascospores are released from the end of April to August (Fig.2, V). Ascospore discharge has a maximum between the end of May and the beginning of June, and shows a close correlation with the amount of precipitation during this period. Empty ascomata begin to deteriorate (Fig. 2, VI) and are often colonized by secondary fungi.

For our investigations Norway spruce needles were collected at more than 800 locations in Europe throughout the natural distribution area

of the tree species, and also in artificial plantations (Fig. 3). *L. piceae* has been found in all needle samples. On the basis of these samples the variability of *L. piceae* has been studied. The morphological characters showed a normal deviation within and between the populations (Osorio & Stephan 1991b). In contrast, cultural studies with more than 450 isolates showed a very large variation of morphological and physiological cultural traits (Osorio & Stephan 1991c). That might be an explanation for the wide distribution of the fungus under different environmental conditions. Summarizing all results of these investigations, one can conclude that the *L. piceae* samples studied from Norway spruce (*Picea abies*) represent just one species.

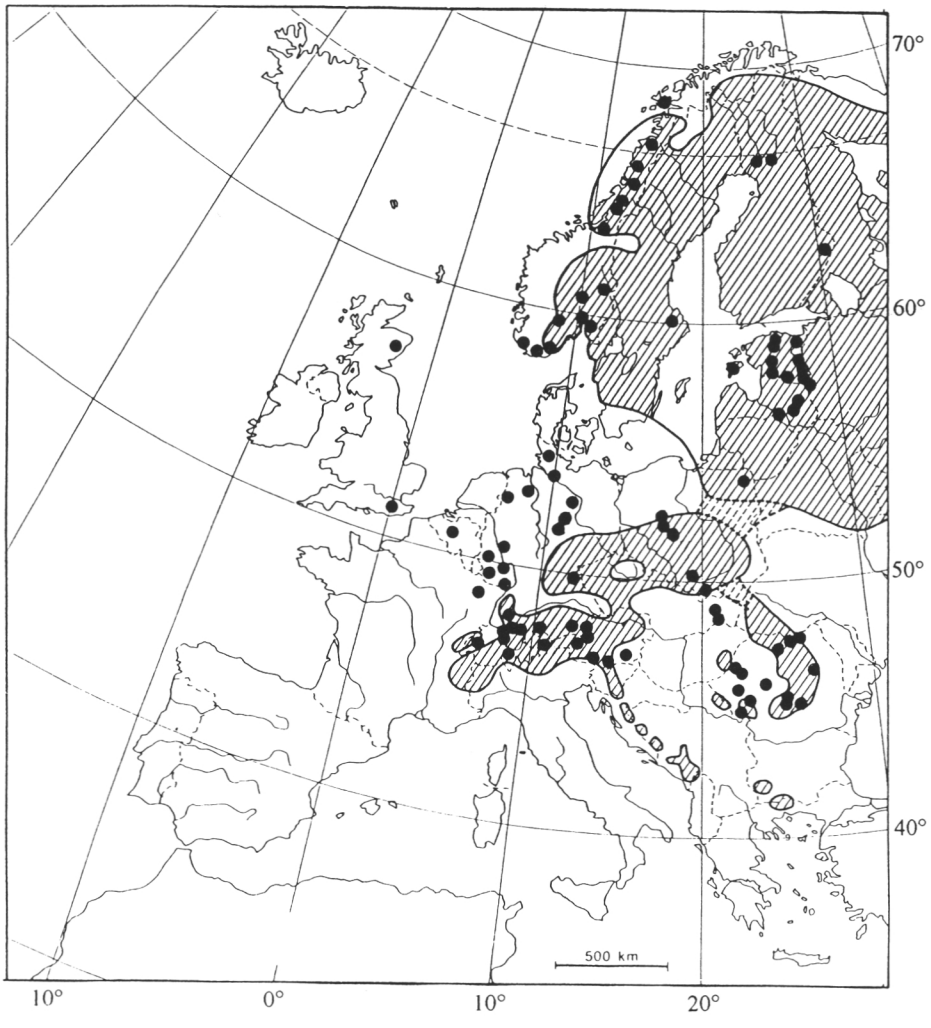

Figure 3. Main collection places of Norway spruce needles with *Lophodermium piceae*. Hatched area = natural distribution range of Norway spruce (*Picea abies*).

References

Butin, H. 1986. Endophytische Pilze in grünen Nadeln der Fichte (Picea abies). Zeitschrift für Mykologie 52: 335–346.

Cannon, P.F. & Minter, D.W. 1984. Lirula macrospora. CMI Descriptions of Pathogenic Fungi and Bacteria, No. 794. 2 p.

Dotzler, M. 1989. Infektionsversuche mit Rhizosphaera kalkhoffii B. und anderen Nadelpilzen an unterschiedlich gestreßten Jungfichten (Picea abies [L.] H. Karst.). Dissertation. University of Munich. 77 p.

Heiniger, U. & Schmid, M. 1989. Association of Tiarosporella parca with needle reddening and needle cast in Norway spruce. European Journal of Forest Pathology 19: 144–150.

Livsey, S. & Barklund, P. 1992. Lophodermium piceae and Rhizosphaera kalkhoffii in fallen needles of Norway spruce (Picea abies). European Journal of Forest Pathology 22: 204–216.

Mack, P. 1989. Endophytische Pilze in Fichtennadeln. Dissertation. University of Munich. 124 p.

Osorio, M. & Stephan, B.R. 1989. Ascospore germination and appressorium formation in vitro of some species of the Rhytismataceae. Mycological Research 93: 439–451.

— & Stephan, B.R. 1990. Zur Taxonomie und Nomenklatur von Lophodermium piceae (Fuckel) v. Höhnel. European Journal of Forest Pathology 20: 355–366.

— & Stephan, B.R. 1991a. Life cycle of Lophodermium piceae in Norway spruce needles. European Journal of Forest Pathology 21: 152–163.

— & Stephan, B.R. 1991b. Morphological studies of Lophodermium piceae (Fuckel) v. Höhnel on Norway spruce needles. European Journal of Forest Pathology 21: 389–403.

— & Stephan, B.R. 1991c. Variation und Verhalten des Fichtennadelpilzes Lophodermium piceae in Kultur. Zeitschrift für Mykologie 57: 215–228.

Rack, K. & Butin, H. 1984. Experimenteller Nachweis nadelbewohnender Pilze bei Koniferen. I. Fichte (Picea abies). European Journal of Forest Pathology 14: 302–310.

Solheim, H. 1988. Fungi on spruce needles in Norway. I. Litterfall samples from the permanent plots of the Norwegian monitoring program for forest damage in 1986. Agaria 9: 55–60.

— 1989. Fungi on spruce needles in Norway. II. Notes about Tiarosporella parca. European Journal of Forest Pathology 19: 189–191.

Stephan, B.R. & Osorio, M. 1993. Considerations about endophytes and artificial inoculations. Proceedings of the Meeting of IUFRO Working Party S2.06-02, Garpenberg, Sweden, June 1991. (in print).

Whitney, H.S., Reid, J. & Pirozynski, K.A. 1975. Some new fungi associated with needle blight of conifers. Canadian Journal of Botany 53: 3051–3063.

Diseases of conifers in Canadian nurseries

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Abstract

Since the early 1960's the numbers of forest nurseries and the annual production of nursery seedlings has increased in Canada. In the early years most seedlings were grown in bareroot nurseries, but since the mid – to late 1970's there has been an even increasing emphasis on production of container-grown seedlings. The latest statistics (Glerum 1990) show that over 75 % of Canada's annual production of 904 million seedlings are grown in containers. This shift in production from bareroot to container nurseries has had a profound effect on the kinds and relative importance of seedling diseases. For example, in bareroot nurseries soil-borne diseases such as damping-off and root rots are of prime importance while seed-borne and shoot diseases such as gray mould (*Botrytis cinerea* Pers.) are most destructive on container-grown seedlings. The decreased importance of soil-borne diseases in container nurseries largely results from the fact that the growing medium (mostly peat) is usually pathogen free. One important reason why shoot diseases are more important on container-grown seedlings is because they are grown at very high densities which favours moisture retention on needles.

The purpose of this presentation is to review the biology, hosts, damage and control of some of the major diseases of conifer nursery seedlings in Canada. Among the bareroot nursery diseases covered are damping-off and *Cylindrocladium* root rot (e.g. *C. scoparium* Morgan) while diseases of container-grown seedlings that are reviewed include gray mould, *Sirococcus* blight (*S. strobilinus* Preuss), the seed or cold fungus (*Caloscypha fulgens* (Pers.) Boudier) and *Fusarium* root rot (mainly *F. oxysporum* Schlecht.). A comprehensive review of these and other nursery diseases, and insects, in Canada is given in a recent paper (Sutherland *et al.* 1991).

References

Glerum, C. 1990. Stock production research in Canada: a historical perspective. Forestry Chronicle 66: 103–111.

Sutherland, J.R., Griefenhagen, S., Juzwik, J. & Davis, C. 1991. Diseases and insects in forest nurseries in Canada. In: Sutherland, J.R. & Glover, S. (eds.). Diseases and insects in forest nurseries. Proceedings of the first meeting of IUFRO working party S2.07-09. Forestry Canada, Pacific and Yukon Region, Pacific Forestry Centre. Information Report BC-X-331. p. 25–32.

Dieback of *Tilia* spp. in Estonia

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Abstract

During last decades an increasing outbreak of a dieback disease on *Tilia* spp., particularly on *Tilia cordata* Mill. has been observed in Baltic states. The disease was found for the first time in Lithuania in 1958. *Thyrostroma compactum* Sacc. was associated with the dieback and regarded as the causal organism (Zuklys & Povilonis 1973). Biology of the fungus was investigated thereupon (Povilonis 1981).

In Estonia, the dieback disease and the associated fungus were discovered in 1975. Before today alternation of several epiphytotics could be observed. An appearance of numerous dead shoots on the branches of lime-trees, often in the middle height of crown could be noticed as the first visible symptom. Adventitious shoots flush around the dead ones and finally bush-like formations will develop spoiling the decorative quality of the trees in parks and weakening the affected trees everywhere. Sometimes crookings and twistings of the branches, not typical for the other dieback diseases, can be visible.

In Lithuania, the disease was injurious only to young trees (Povilonis 1981). In Estonia it occurs on trees of various age. In Lithuania *T. compactum* was found on *Ulmus* spp., too in Estonia only on *Tilia* spp. The disease is likely moving to North and West. Investigations on the etiology of the dieback disease as well as the taxonomy and actual role of the associated fungus in the disease are needed.

References

Povilonis, R.P. 1981. Biology of Thyrostroma compactum Sacc. and its utilization for the restriction of the damage caused to lime trees in Lithuanian SSR. Author´s summary to the dissertation of the candidate of biological sciences, Vilnius. 15 p. (In Russian).

Zuklys, L. & Povilonis, R. 1973. Thyrostromoses of lime-trees (Thyrostroma compactum Sacc.). Short reports of the XIX Scientific Conference of the Lecturers of the Lithuanian Agricultural Academy, Kaunas. p. 204–205. (In Lithuanian).

Infection by *Heterobasidion annosum* in fine roots of spruce; use of ELISA for detection and effects on chitinase and peroxidase activity

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Abstract

The increased concentration of total *Heterobasidion annosum* (Fr.) Bref. antigenic material in colonised roots as detected with enzyme linked immunosorbent assay (ELISA) was found to correlate with manifestation of disease symptoms in infected plants. Chitinase activity measured as release of soluble oligomers from ^{3}H-chitin suspension was found to increase 48 h after infection of seedling fine roots with the germinating spores of *H. annosum*. A similar observation was made for extractable activity of root tissue peroxidase – an enzyme implicated in lignin synthesis. Analysis for isoforms of chitinase on isoelectric focusing gels revealed a single constitutively produced protein band in both challenged and mock inoculated seedlings. Peroxidase isoforms were detected and one isozyme was suspected to be an infection related enzyme.

Introduction

Pathogenesis-related proteins (PRP) are induced in plants as a defence response to either microbial infection or abiotic stress factors (Albersheim & Valent 1978, Pan *et al.* 1991, Beissmann *et al.* 1992). Mechanisms and recognition of defence signals are well documented on agricultural crop plants. Earlier works on annual crops have attributed induced resistance by plants during infection to increased levels of chitinase, peroxidase and ß-1,3-glucanase activities (Wyatt *et al.* 1991). However, limited studies have been done on physiological response of perennial, especially woody plants, to microbial infection. Previous works have reported on cell wall alterations such as suberization as disease resistance mechanisms in tissues of perennial plants (Pearce 1991).

Some investigations concerned infection after mechanical wounding of bark of standing trees (Woodward & Pearce 1988a, 1988b, Lindberg & Johansson 1991, Lindberg *et al.* 1992). Results of such studies are subject to a lot of environmental and other stress influences. This may explain variations of data from different laboratories.

Chemical and biological measures for the control of infection and damage caused by *Heterobasidion annosum* (Fr.) Bref. on economically

important tree species especially conifers are currently at a trial stage. Such control measures must be based on biochemical understanding of the infection biology of this pathogen as well as resistance systems in woody perennials. The aim of the present study is twohold, firstly to find out if it is possible to use an ELISA method with antibodies produced against *H. annosum* cell wall material to make an assessment of the invasion of pathogen in fine roots of spruce; secondly a more longterm goal is to characterise biochemically defence reactions occurring in spruce roots when the plant is challenged with fungal infection.

Material and methods

Plant material and infection procedure

Spruce (*Picea abies* (L.) H. Karst.) seeds were surface sterilised with 30 % H_2O_2 and sown in batches of 20 on sterile 1 % water agar in 90 mm (diameter) plates. Thereafter they were left to germinate in the dark at 22 °C. Germinated seedlings (4–7 d old) in batches of 10 were transplanted aseptically onto another sterile water agar plate, and the roots were inoculated with 10^6 pregerminated conidiospores per ml of *H. annosum*. The root region of inoculated plants was covered with sterile moist filter paper. Control seedling roots were mock inoculated with sterile distilled water. Plates were incubated in a growth chamber at 20 °C, at a photoperiod of 16 h, 200 µE m^{-2} s^{-1}.

Preparation of crude extracts for enzyme and ELISA assay

Duplicate sets of plates were removed at various periods after infection, roots were excised and homogenised on ice in a mortar in the presence of 0.1 M Tris –HCl buffer (pH 7.6) containing 1 % w/v polyvinylpyrollidone (PVP 360,000). The homogenate was centrifuged at 4000 x g for 10 min and the supernatant was used for enzyme and ELISA assay.

Peroxidase activity was colorimetrically determined as follows: Crude extract (200 µl) was added to 3 ml substrate solution (0.03 M guaiacol in 0.08 M phosphate buffer, pH 6 and 0.03 % H_2O_2). The mixture was vigorously mixed and the increase in absorbance read at 470 nm at room temperature. Enzyme activity was estimated as O.D min^{-1} mg^{-1} protein.

Chitinase assay was determined using ^{3}H-chitin as substrate. Crude extracts (200 µl) was mixed with 1 ml of ^{3}H-chitin suspension (15 mg ml^{-1}) in phosphate buffer (0.05 M, pH 6.4). The mixture was incubated for 4 h at 37 °C. The reaction was terminated by addition of 1.5 ml of 10 % trichloroacetic acid (TCA) and the solution centrifuged at 4000 x g for 30 min. The radioactivity in the supernatant was

determined using a Beckman scintillator counter. Enzyme activity was calculated as cpm mg^{-1} protein.

Protein was determined using the method described by Bradford (1976) with bovine serum albumin (BSA) as reference protein. Immunogenic material (mycelial) was isolated from *H. annosum* and antibodies were raised against it in rabbits according to the method described by Breuil *et al.* (1988). Enzyme linked immunosorbent assay (ELISA) was carried out according to the method described by Daniel & Nilsson (1991). Disease symptoms were assessed by visual inspection (Table 1).

Gel Electrophoresis

Isoelectric focusing was carried out using the Phast system (Pharmacia, Sweden) with separations at pH 3 to 9.

Peroxidase was detected as described by Holden & Rohringer (1985) except that the chromogenic substrate solution contained in addition to 0.06 % (w/v) 4-chloro-1-naphthol, 0.03 % H_2O_2 and 20 % ethanol in 0.05 M phosphate buffer (pH 6.0).

Chitinase isozymes were visualised by immunoblotting (Biorad Kit: First antibody (1:1000) was chitinase antibody; second antibody (1:1000) was goat antirabbit (lgG) conjugated with horseradish peroxidase (HRP)). A chitinase antibody raised against sugar beet chitinase was kindly supplied by Danisco, Denmark.

Table 1. The relationship between *Heterobasidion annosum* mycelial antigens (detected by ELISA) and manifestation of disease symptoms.

Period after infection[a]	ELISA reading[b] (A_{405})	Disease symptoms[c]
3	0.198	Browning and necrosis of root, cortical tissues colonised, stellar cells unaffected
10	0.515	Less than 3 % of germlings showing signs of wilting, shrinking of cortical cells
14	0.753	Wilting, loss of shoot turgor, flaccidity of root region, destruction of stellar cells

a) Procedure according to Daniel & Nilsson (1991), with first antibody at 1:100; second antibody at 1:1000.
b) ELISA values are average of two adjacent wells.
c) Details of disease symptoms as revealed by immunohistochemical staining (unpublished).

Results and discussion

Detection of the pathogen with ELISA

Antibodies raised against pathogen antigens have successfully been used in diagnosis of several plant diseases (Clark & Adams 1977). In order to find out if we could use this technique to monitor the extent of colonisation of spruce roots by the rot fungus, we raised antibodies against cell wall preparations from *H. annosum*. The amount of antigen in spruce root extracts was then quantified using the ELISA method. *H. annosum* antigen could be detected in extracts from spruce roots at an early stage after infection (Table 1). The amounts of antigen increased drastically with infection time. The increase correlated with the severity of damage to internal tissues as detected with immuno-histochemical methods (not shown) and manifestation of disease symptoms as visually observed. The results indicated that the method is useful for detection of *H. annosum* and it might become especially useful in the field to distinguish between abiotic stress and fungal infection.

Peroxidase and chitinase activities in spruce roots

Enzyme extracts from fine roots of spruce exhibited both peroxidase and chitinase activity throughout development (Figs. 1 and 2). Two days after inoculation with fungal spores, the activities of both types of enzymes increased. For at least three further days, these enzymes remained at a slightly higher level in infected roots as compared to the activities in the control roots.

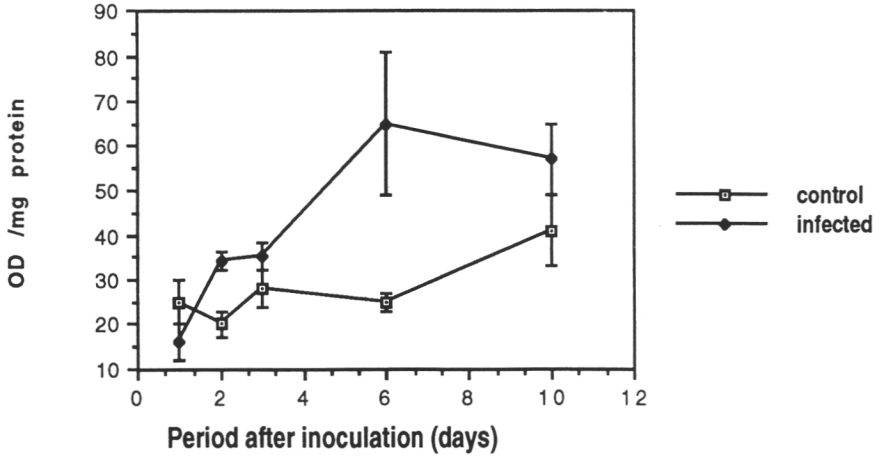

Figure 1. Peroxidase activity of fine roots of spruce following infection by *Heterobasidion annosum*.

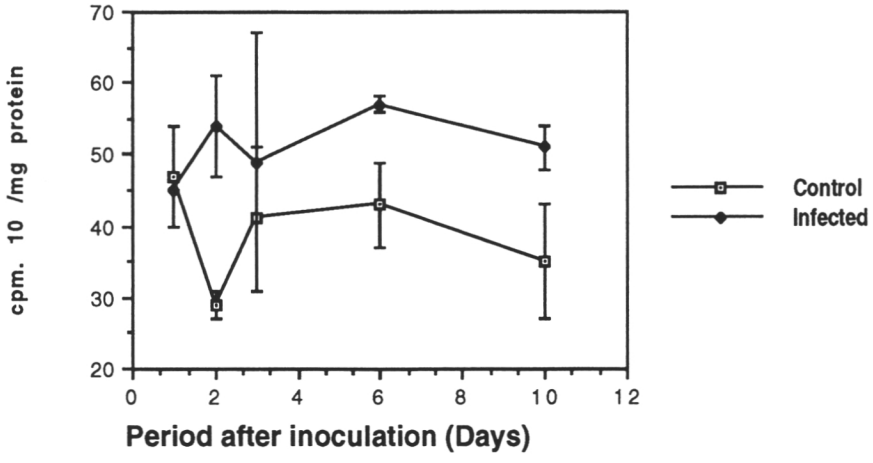

Figure 2. Chitinase activity of fine roots of spruce following infection by *Heterobasidion annosum*.

To find out if the response was age dependent, we determined the effect of inoculation on chitinase activity, when infection occurred at a later developmental stage (27 day old roots). The results (Fig. 3) indicated that the older roots reacted similarly as the 7 day old roots.

The recorded increases in chitinase and peroxidase activities may be attributed to specific forms of the respective enzyme. To investigate this point further, we subjected enzyme extracts to separation on isoelectric focusing gels and either stained the gels for peroxidase activity or tried to localise chitinase bands by immunoblotting.

Efforts to identify separate isoforms of chitinase were not successful, since only one chitinase band was seen in extracts from either control or infected roots. This band was at the point of application, indicating that the chitinase enzyme(s) did not migrate in the gel. Similarly, after treatment with sodium dodecylsulphate (SDS), and electrophoresis in SDS gels, only one, non migrating, chitinase band was detected in the immunoblotting. At present, we have no explanation for these observations.

Staining for peroxidase activity gave 9 acidic and 2 basic peroxidase bands, in extracts from either control or infected plants (Fig. 4). One acidic band, at pH 5.75 (indicated in Fig. 4) appeared denser in extracts from infected roots. However, a more careful investigation is needed to find out if this difference is reproducible.

In conclusion, further studies are required to characterise the role of chitinase and peroxidase in disease resistance. To find out if specific isoforms of chitinase are induced, we need to solve the problem of aggregation of the enzyme(s). One further point that especially deserves investigation is the subcellular localisation of the peroxidase and

chitinase activities in spruce roots. One might speculate that at least some of the forms of these enzymes are located in the extracellular space, in which case selective and stepwise extraction methods more clearly might reveal differences between control and infected roots.

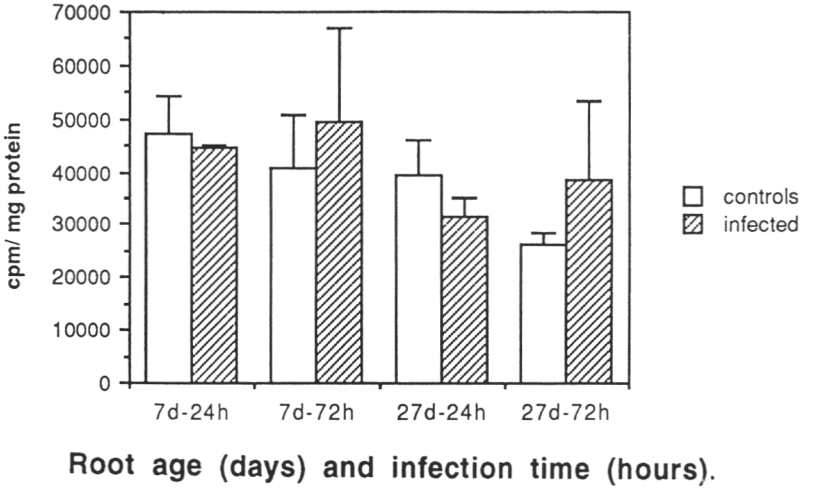

Figure 3. The relationship between root age and response of spruce seedling to infection by *Heterobasidion annosum* (determined as changes in chitinase activity).

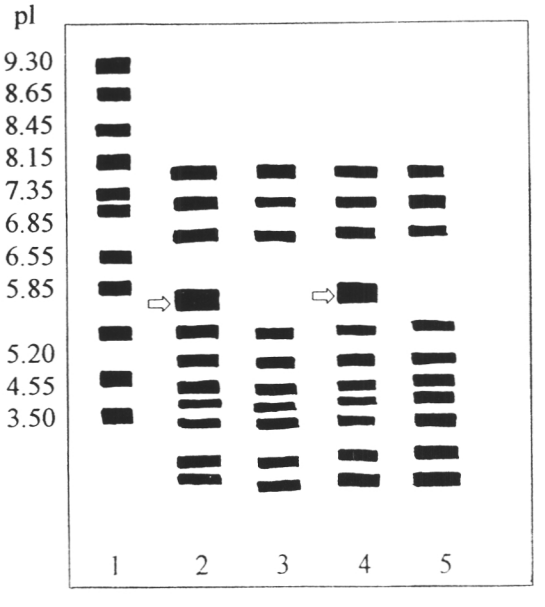

Figure 4. Peroxidase isozymes in crude extracts from treated spruce roots. Lane 1: isoelectric points of calibration. Lane 2: 9 d old root infected for 12 days. Lane 3: 9 d old root noninoculated. Lane 4: 15 d old root infected for 14 days. Lane 5: 15 d old root noninoculated.

References

Albersheim, P. & Valent, B.S. 1978. Host-pathogen interactions in plants. The Journal of Cell Biology 78: 627–643.

Beissman, B., Engels, K., Marticke, K-H. & Reisener, H.J. 1992. Elicitor-active glycoproteins in apoplastic fluids of stem rust infected wheat leaves. Physiological and Molecular Plant Pathology 40: 79–89.

Bradford, M.M. 1976. A rapid and sensitive method for the quantification of microgram quantities of protein using the principle of protein dye binding. Analytical Biochemistry 72: 248–254.

Breuil, C., Yamada, J., Seifert, K.A. & Saddler, J.N. 1988. An enzyme linked immunosorbent assay (ELISA) for detecting staining fungi in unseasoned wood. Journal of Institute of Wood Science 11: 132–134.

Clark, M.F. & Adams, A.N. 1977. Characteristics of the microplate method of enzyme linked immunosorbent assay for the detection of plant viruses. Journal of General Virology 34: 475–483.

Daniel, G. & Nilsson, T. 1991. Antiserum to the fungus Phialophora mutabilis and its use in enzyme-linked immunosorbent assays for detection of soft rot in preservative-treated and untreated wood. Phytopathology 81(10): 1319–1325.

Holden, D.W. & Rohringer, R. 1985. Peroxidases and glycosidases in intercellular fluids from noninoculated and rust affected wheat leaves. Plant Physiology 79: 820–824.

Lindberg, M. & Johansson, M. 1991. Growth of Heterobasidion annosum through bark of Picea abies. European Journal of Forest Pathology 21: 377–388.

— , Lundgren, L., Gref, R. & Johansson, M. 1992. Stilbenes and resin acids in relation to the penetration of Heterobasidion annosum through the bark of Picea abies. European Journal of Forest Pathology 22: 95–106.

Pan, S.Q., Ye, X.S. & Kuc, J. 1991. Association of ß-1,3-glucanase activity and isoform pattern with systemic resistance to blue mold in tobacco induced by stem injection with Peronospora tabacina or leaf inoculation with tobacco mosaic virus. Physiological and Molecular Plant Pathology 39: 25–39.

Pearce, R.B. 1991. Reaction zone relics and the dynamics of fungal spread in the xylem of woody angiosperms. Physiological and Molecular Plant Pathology 39: 41–55.

Woodward, S. & Pearce, R.B. 1988a. The role of stilbenes in resistance of sitka spruce (Picea sitchensis (Bong.) Carr. to entry of fungal pathogens. Physiological and Molecular Plant Pathology 33: 127–149.

— 1988b. Wound associated response in sitka spruce root bark challenged with Phaeolus schweinitzii. Physiological and Molecular Plant Pathology 33: 151–162.

Wyatt, S.E., Pan, S.Q. & Kuc, J. 1991. ß-1,3-glucanase, chitinase and peroxidase activities in tobacco tissues resistant and susceptible to blue mold as related to flowering age and sucker development. Physiological and Molecular Plant Pathology 39: 433–440.

Host-pathogen interaction in the roots of Norway spruce

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Abstract

Occurrence of severe root dieback on Norway spruce (*Picea abies* (L.) H. Karst.) seedlings has been reported from several Norwegian forest nurseries at the beginning of the eighties. Among other fungi, *Pythium* sp. has been repeatedly isolated from diseased seedling roots. In pathogenicity tests it appeared to be highly pathogenic, causing growth inhibition, wilting, root decay and death of seedlings within 12 days.

On background of this study, roots of *Picea abies* infected with *Pythium* sp. have been chosen as an experimental system to study the host-pathogen interaction at the molecular level. Aseptic spruce seedlings were grown in homogenized mycelial slurry of *Pythium* sp. Seedlings infected in this system suffered from the same disease symptoms as mentioned above. Roots were sampled 1, 2, 3, 4, 6 and 10 days after infection and low-pH-soluble proteins from both infected and control roots were extracted. They were resolved on isoelectrofocusing (IEF) gels. Chitinase and ß-1,3-glucanase enzymatic assays have been performed on the gels after IEF.

Our results indicate induction of more than 30 different pathogenesis-related (PR) proteins in the infected roots. Already one day after infection the appearance of proteins with high pIs and low pIs was detectable. The number and amount of proteins increased considerably by the third day and remained stable further on. In control plants only two acidic proteins were detected. Eight different isoforms of chitinases were produced specifically upon pathogen infection. Two acidic chitinases were constitutively expressed, however, they became strongly induced after infection. Two pathogen induced acidic ß-1,3-glucanases were detected.

Apparently, induction of specific PR-proteins and synergistic action of both chitinases and glucanases is a part of defence system in gymnosperms against pathogens. Whether plants respond in the same way to non-pathogenic colonization or abiotic stress remains to be seen.

Natural antagonists to *Heterobasidion annosum*

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Abstract

A review of search for natural antagonists to the root rot fungus *Heterobasidion annosum* (Fr.) Bref. is given including the data from the previous USSR. In the Estonian Forest Research Institute 76 isolates of fungi belonging to *Aphyllophorales* and *Agaricales* have been tested *in vitro*. 8 isolates as promising antagonists were selected for the following experiments *in vivo*.

Introduction

A number of micro-organisms have been tested *in vitro* to find natural antagonists to *Heterobasidion annosum* (Fr.) Bref. (Table 1). Some of them are of interest from the standpoint of biological control, i.e. they might hopefully suppress the pathogen *in vivo* as well. Several strains of *Phlebia gigantea* (Fr.) Donk. have proved to be useful for this purpose.

The ecological niche, in which *H. annosum* is found contains a huge number of various organisms, whose relation to the pathogen is not yet investigated in any way. Many wellknown investigations in this field have been carried out in western countries. In the previous USSR the research work of this kind has been even popular in the last decades.

Higher plants

As a rule the influence of phytoncids of higher plants to *H. annosum* in pure culture is very weak. Vasiliauskas (1989) in Lithuania showed that phytoncids of leaves of *Ranunculus acer* L. inhibited essentially in *in vitro* experiments the growth of *H. annosum*. Water-extracts of leaves and roots of forest trees and shrubs commonly stimulated the growth of mycelium and germination of spores of the pathogen, only *Robinia pseudoacacia* L. and *Amorpha fruticosa* L. had a strong antagonistic influence to *H. annosum* and these species were recommended to plant between the conifers in sites with high risk of root rot.

Shatjajev (1984) in Kazakhstan established that water-extracts from *Artemisia pontica* L., *Pulsatilla flavescens* Zucc., *Cnidium dubium* Thell., *Calamagrostis epigeios* (L.) Roth, *Turritis glabra* L., *Cannabis ruderalis* Janish and *Jurinea cyanoides* (L.) Rehb. decreased the vegetative

growth of *H. annosum* up to 70–100 %. Among shrubs in Kazakhstan the strongest inhibitors were *Salix xerophila* B. Flod. and *S. acutifolia* Willd.

Table 1. Fungi and actinomycetes which have been tested *in vitro* towards *Heterobasidion annosum* (by various authors, the source of information is given in Hanso & Hanso 1985).

Species	
Actinomyces sp.	*Mucor hiemalis*
Agaricus bisporus	*Penicillium claviforme*
Ascomyces sp.	*Penicillium glaucum*
Beauveria bassiana	*Penicillium sp.*
Beauveria tenella	*Phlebia gigantea*
Bjerkandera adusta	*Phycomyces blakesleanus*
Boletus bovinus	*Polyporus adustus*
Boletus variegatus	*Polyporus melanopus*
Botrytis cinerea	*Radulomyces confluens*
Cladobotryum mycophilum	*Resinicium bicolor*
Coniophora puteana	*Rhodotorula rubra*
Coriolellus squalens	*Saccharomyces pastorianus*
Coryne sarcoides	*Scutalidium lignicola*
Fomitopsis pinicola	*Sistotrema brinkmannii*
Gloeophyllum abietinum	*Stereum sanguinolentum*
Gloeophyllum odoratum	*Streptomyces griseus*
Hirschioporus abietinus	*Torula colliculata*
Hypholoma capnoides	*Trametes versicolor*
Hypholoma fasciculare	*Trichoderma alba*
Hypholoma sp.	*Trichoderma lignorum*
Hypomyces broomeanus	*Trichoderma viride*
Kloeckera corticis	*Trichoderma sp.*
Lenzites sepiaria	*Zygorrhynchus moelleri*

Soil micro-organisms, mycorrhizal fungi

The comparative analysis of soil microflora in several stands growing on permanent forest and on previous arable lands in Lithuania showed that microflora, isolated from the soils of earlier agricultural use indicated neutral or weak antagonistic activity against the root rot fungus, whereas the microflora, isolated from old forest land possessed a high antagonistic activity. 24 % of *Penicillium* spp. and 35 % of *Trichoderma spp.* were strong and 54 % of *Trichoderma* spp. very strong antagonists to the pathogen (Vasiliauskas 1989). Davidenko & Tjunova (1989) investigated the influence of soil micro-organisms to *H. annosum* in pine stands of Central Russia. They established that 30 % of soil micro-organisms stimulated, 50 % were indifferent and 20 % inhibited the vegetative growth of mycelium and germination of conidia of *H. annosum*. Less than a half of the inhibitors was able to destroy patho-

gen's tissues as well. The antibiotic activity of soil against *H. annosum* was increased by *Bacillus subtilis* (Ehrenberg) Cohn, *B. cereus* Fraunl. & Frankl. and by some fungi belonging to *Trichoderma, Mucor, Zygorrhynchus, Aspergillus* and others.

Mycorrhizal fungi are mostly indifferent or weak antagonists towards *H. annosum*. Gundajeva *et al.* (1981) found that their biopreparation (active species of which was *Macrolepiota procera* (Fr.) Sing. as it became clear afterwards – oral communication) inhibited the root rot development and was recommended to use for biological control by artifical inoculation of the rhizosphere of pine seedlings.

Wood decaying fungi

There are some other wood decaying fungi besides wellknown *Phlebia gigantea* which were tested in the previous USSR as antagonists to *H. annosum*: *Irpex fusco-violaceus* (Fr.) Fr., *Stereum sanguinolentum* (Fr.) Fr., *Trametes squalens* Karst. (Kljushnik 1962), and *Fomitopsis pinicola* (Fr.) Karst. (Darijtchuk *et al.* 1981). Some wood-decomposing fungi were already recommended for biological control (Table 2).

Table 2. Fungal antagonists to *Heterobasidion annosum* recommended for the biological control against the root rot fungus in the previous USSR.

Coriolellus squalens (P. Karst.) Bond. et Sing. (syn. *Trametes squalens* Karst.) A. Shatjajev, Kazakh Institute of Forestry and Agromelioration, Stchutchinsk. The author's license No 1153404 CCCP
Hirschioporus abietinus (Fr.) Donk. Biopreparation "HIRCHIOPORIN" L. Filtchakov, Institute of Plant Physiology of the Ukrainian Academy of Sciences, Kiev. The author's license No 904641 and 906062 CCCP
Phlebia gigantea (Fr.) Donk. Biopreparation "GIRIONIS-1" A. Vasiliauskas, Lithuanian Forest Research Institute, Kaunas (Girionis).
Phlebia gigantea J. Polestchuk, Belorussian Technological Institute, Minsk. The author's license No 907068; MKU3C12N1/02 CCCP
Pleurotus ostreatus (Fr.) Kumm. J. Polestchuk Application for an author's license No 3587797/13 CCCP
Trametes flavescens (syn. *Coriolellus flavescens* (Bres.) Bond. et Sing.) J. Polestchuk The author's license No 1225067; MKU3AO1N63/00 CCCP

Table 3. Isolates of fungi tested in Estonian Forest Research Institute in search of antagonists to *Heterobasidion annosum*.

No	Species	Isolate	Effect	No	Species	Isolate	Effect	No	Species	Isolate	Effect
	APHYLLOPHORALES			27.	*P. centrifuga*	B61	+	53.	*Hygrophoropsis sp.*	B222	–
1.	*Auriscalpium vulgare*	B191	+		*AGARICALES*			54.	*Kuechneromyces mutabilis*	B76	–
2.	*Coltricia perennis*	B223	–	28.	*Agaricus bisporus*	B10	–	55.	*Laccaria laccata*	B128	+
3.	*Fomitopsis pinicola*	B3	+	29.	*Agaricus sp.*	B203	–	56.	*L. laccata*	B195	–
4.	*F. pinicola*	B13	–	30.	*Agaricus sp.*	B204	–	57.	*L. laccata*	B211	–
5.	*F. pinicola*	B48	+	31.	*Amanita muscaria*	B213	+	58.	*Lepista nuda*	B82	–
6.	*F. pinicola*	B70	+	32.	*A. porphyria*	B232	–	59.	*L. nuda*	B175	–
7.	*F. pinicola*	B71	+	33.	*Amanita verna*	B141	+	60.	*L. nuda*	B219	–
8.	*F. pinicola*	B72	+	34.	*Coprinus atramentarius*	B52	–	61.	*Macrolepiota procera*	B46	–
9.	*F. pinicola*	B73	–	35.	*C. atramentarius*	B59	–	62.	*Macrolepiota procera*	B47	+
10.	*F. pinicola*	B74	+	36.	*C. disseminatus*	B92	+	63.	*M. rhacodes*	B49	+
11.	*F. pinicola*	B86	+	37.	*C. comatus*	B9	–	64.	*Macrolepiota sp.*	B190	–
12.	*F. pinicola*	B161	–	38.	*C. comatus*	B185	–	65.	*Naematoloma fascic.*	B60	–
13.	*F.pinicola*	B184	–	39.	*Coprinus sp.*	B20	+	66.	*Panaeolus subbalteatus*	B55	–
14.	*F. rosea*	B2	–	40.	*Coprinus sp.*	B35	–	67.	*Panaeolus sp.*	B93	–
15.	*Gloeophyllum sepiarium*	B16	–	41.	*Coprinus sp.*	B38	+	68.	*Paxillus involutus*	B214	–
16.	*Hericium coralloides*	B88	–	42.	*Coprinus sp.*	B40	–	69.	*Phaeolepiota aurea*	B69	+
17.	*Hirschioporus abietinus*	B68	+	43.	*Coprinus sp.*	B51	+	70.	*Phyllotopsis nidulans*	B216	–
18.	*H. abietinus*	B85	+	44.	*Coprinus sp.*	B58	–	71.	*Pleurotus ostreatus*	B147	+
19.	*Ischnoderma benzoinum*	B26	–	45.	*Coprinus sp.*	B77	+	72.	*P. ostreatus*	B153	–
20.	*Lenzites betulina*	B227	–	46.	*Coprinus sp.*	B79	+	73.	*Stropharia aeruginosa*	B83	+
21.	*Phellinus punctatus*	B75	–	47.	*Coprinus sp.*	B91	+	74.	*S. aeruginosa*	B162	–
22.	*Phlebia gigantea*	B30	+	48.	*Coprinus sp.*	B205	+	75.	*S. hornemannii*	B193	–
23.	*P. gigantea*	B31	–	49.	*Coprinus sp.*	B207	+	76.	*S. hornemannii*	B194	–
24.	*P. gigantea*	B62	–	50.	*Coprinus sp.*	B209	+				
25.	*P. gigantea*	B64	+	51.	*Cortinarius armillatus*	B87	+				
26.	*P. gigantea*	B63	+	52.	*Hygrocyde conica*	B81	–				

The search of natural antagonists to *Heterobasidion annosum* in Estonia

In the Estonian Forest Research Institute we have tested 76 strains of fungi belonging to 56 species of *Aphyllophorales* and *Agaricales* (Hanso & Hanso 1985, 1992). The effect of retardation was established by comparing the growth of dualculture (under test fungus + *H. annosum*) and monoculture (*H. annosum* + *H. annosum*) on malt agar (pH 6.0) at temperatures 1, 17 and 27 °C. The strains, which suppressed the growth of pathogen more than 50 % are marked in Table 3 by the sign "+". 8 isolates were selected as strong antagonists and taken for following experiments *in vivo*. Biopreparations from these antagonists were used for the treatment of substratum in containers before sowing spruce and pine seeds as well for the infection of the open nursery soil. One of the isolates (*Amanita verna* (Fr.) Pers. ex Vitt. s. Fr.) suppressed the growth of *H. annosum* but reduced the growth of spruce and pine seedlings as well. It was left out of the following experiments. The other selected isolates increased the growth of conifer seedlings. Last year about 10 000 of 2- and 3-year old seedlings were infected with the selected antagonists – mycorrhiza forming fungi. Infected seedlings have shown up to one third faster growth on poor sandy nursery soil than untreated plants. Increased growth of the seedlings was only an achievement of secondary importance – the main purpose was to increase the resistance of seedlings against the root rot. Inoculated pine and spruce plants in forest plantations will be followed during many years to establish the success of artificial inoculation and to investigate the hopeful retardation of damage.

References

Darijtchuk, Z.S., Seliverstov, A.V. & Tribun, P.A. 1981. Griby-antagonisty dlja biologitsheskoi borby s kornevoi gubkoi v lesah Ukrainskih Karpat. Zastchita hvoinyh nasazhdenii ot kornevyh gnilei. Minsk. p. 25–26.

Davidenko, M.B. & Tjunova, M.I. 1989. Antagonisticheskaja aktivnost potshvennyh i rizosfernyh mikroorganizmov v otnochenii Heterobasidion annosum (Fr.) Bref. Mikologija i fitopatologija 23(5): 454–458.

Gundajeva, J.I., Krangauz, R.A. & Jurgenson, L.E. 1981. Effektivnost biologitsheskih i himitsheskih mer profilaktiki i borby s kornevoi gubkoi. Nadzor za vrediteljami i boleznjami lesa i sovershenstvovanie mer borby s nimi. Moskva. p. 48–50.

Hanso, M. & Hanso, S. 1985. Poisk antagonistov kornevoi gubki. Metsanduslikud uurimused 20: 122–152.

— & Hanso, S. 1992. Poisk antagonistov kornevoi gubki II. Metsanduslikud uurimused 25: 124–142.

Kljushnik, P.I. 1962. Kornevaja gubka i mery borby s nei. Moskva. 40 p.

Shatjajev, A.V. 1984. Ispytanie biologitsheskih sredst borby s kornevoi gubkoi b lentotshyh borah. Vestnik selskohozjaistvennoi nauki Kazakhstana 5: 76–77.

Vasiliauskas, A. 1989. Kornevaja gubka i ustoichivost ekosistem hvoinyh lesov. Vilnius. 175 p.

Avoiding infection of thinning stumps by *Heterobasidion annosum*

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Abstract

Various ways of reducing stump infection by *Heterobasidion annosum* (Fr.) Bref. after thinning are reviewed, including selection of season for harvest, biological and chemical control. Also, some results from Swedish investigations about stump protection are presented. In Fennoscandia, the risk of stump infection after thinning is very low during October–March. April–September treatment of stumps with 30 % urea solution is recommended, which will reduce the infection rate by at least 80–90 %. Other chemicals, including a fungicide, have also been tested in a smaller scale.

Introduction

When the root rot fungus, *Heterobasidion annosum* (Fr.) Bref. once has entered living bark, or living or dead wood in the root, it is too late to stop its attack. However, the fungus has difficulties before reaching this stage of infection, both because of the resistance of the dead bark and because of competing micro-organisms. The problem for the fungus is the primary establishment.

In unthinned first generation stands of Norway spruce (*Picea abies* (L.) H. Karst.) or Scots pine (*Pinus sylvestris* L.), attacks by *Heterobasidion* are rare but may occur in trees, killed or stressed by other biotic or abiotic factors. In contrast, in thinned stands and particularly in old forest land the root rot frequency may be high. The rate of spread is dependent on the presence of decayed stumps, the density of the stand, the structure of the root system, the soil type and the vigour of the tree and its roots.

The major parts of the forests have passed many generations and there have been enormous possibilities for the fungus to establish and to spread. The main problem as to root rot in our countries is that the fungus is already there and can survive and spread within and between generations. Efforts to limit this stage of disease have been rather fruitless – particularly in respect of economy. The efforts have therefore been concentrated on first generation stands in order to avoid the entrance of the pathogen. The pioneer work done in Great Britain, Denmark and Finland have been promising at least from the biological

point of view. It has been concentrated on preventing the fungal basidiospores from entering fresh stump surfaces and on conditions governing the risk for infection.

Environmental conditions and stump infection frequency

The seasonal incidence of stump infection has been investigated for Scots pine (Rishbeth 1951, Meredith 1959) and for Norway spruce (Yde-Andersen 1962, Kallio 1970). Redfern (1989) found that wood moisture content of the stump strongly influenced the level of infection: heavy rainfall is likely to reduce the frequency.

In spite of variations in the spore deposition, most interesting is when germinating spores have overcome the chemical, structural and biological defence on or beneath the stump surface and are advancing downwards.

An investigation of the incidence of *H. annosum* in stumps about one year after the first thinning was made in various seasons. When estimating the percentage of infected stumps in relation to season, the temperature of the day of thinning was the most important factor influencing the infection rate (Fig. 1.).

The results support the importance of selecting proper seasons and weather conditions for thinning – and of course for clear-cutting in stands with low infection.

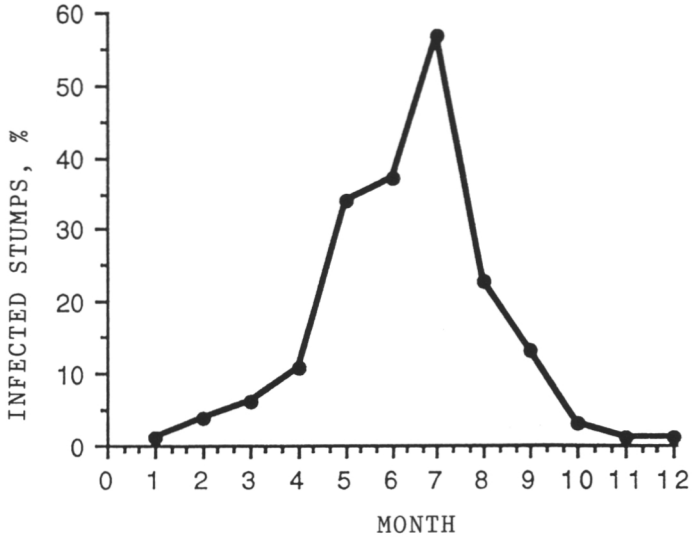

Figure 1. Percent infected spruce stumps one year after thinning at various seasons.

Biological control

As climate and local weather in most of Europe do not allow a selection of favourable thinning conditions, other means for preventing stump infection have been tested during the years.

The discovery of *Phlebia gigantea* (Fr.) Jül. as an ideal competitor to *H. annosum* on pine stumps (Rishbeth 1963, Greig 1976) has not been successfully applied for spruce stump protection. An efficient competitor must penetrate the whole stump volume homogenously and at a speed surpassing that of *H. annosum*, and stop it before it reaches living wood, where *H. annosum* is much more efficient. This is the case for *P. gigantea* in pine but not in spruce wood. For spruce stumps, Holdenrieder (1984) tested other decay fungi with various properties in common with *P. gigantea*. *Hypholoma capnoides* (Fr.) Kumm., *Bjerkandera adusta* (Willd. ex Fr.) Karst., *Resinicium bicolor* (Alb. & Schw. ex Fr.) Parm. and also *Trichoderma* species – showed antagonism near the inoculum, but only *R. bicolor* colonized the stump wood. *H. capnoides* restricted the growth of *H. annosum* at least on the stump surface. *R. bicolor* is at present tested by us with some progress as competitor to *H. annosum* in spruce roots.

These results show the difficulties in biological control: in general each fungal species has its own pattern to spread in the wood depending on specific ecological demands: optima for nutrients, humidity, temperature, structural and chemical factors etc. Therefore, the fungi can grow side by side without interfering with each other in the wood – even if they seem to compete on a surface.

Chemical control

There are lots of chemicals potentially capable of preventing fungal growth on a stump surface. Our demands are however hard: they must be nontoxic, harmless, cheap, easily applied, not decay preventing etc.

Several compounds have been tried, like urea, nitrite, sodium tetraborate (borax), ammonium sulphamate. Urea at 20–35 % concentration is most commonly used in Europe. However, the use has not been preceded by practical tests in a scale large enough. The results reported show a high variation, probably depending on the assay period, application method and amount applied.

We have tested urea in connection with thinnings made during the vegetation period. The effect was evaluated after about one year as the decrease in the percentage of infected stumps – 5 cm below the stump surface. A significant effect was obtained only when the concentration was higher than 15 %. However, for a stable good effect 30 % was needed. In general the infection rate was decreased by about 90 %.

Borax is known as a very efficient protectant and has been successfully tested in England (Pratt) and also by us in a small scale.

Some experiments have also been performed with other chemicals as to their effect on conidiospore germination of *H. annosum* and on preventing growth of this fungus in spruce stems. An experiment with stem pieces treated with the chemicals and then inoculated with conidia showed after 25 days that 5 % $FeCl_3$, or 0.05 % Plantvax (a fungicide) were as efficient as borax and urea.

At present an experiment is performed to evaluate the persistence of urea in the stump, its effect on the stump pH, on urease activity and on the microflora. Urea causes a rapid rise of pH to about 7.5 and has a strong buffering effect. Urease activity seems to increase, probably because of selection of urease-producing bacteria. However, the microflora has not yet been shown to be affected by urea – one reason may be the very dry weather, resulting in absolutely no visible fungal growth on the stump surface.

References

Greig, B. 1976. Biological control of Fomes annosus by Peniophora gigantea. European Journal of Forest Pathology 6: 65–71.

Holdenrieder, O. 1984. Untersuchungen zur biologische Bekämpfung von Heterobasidion annosum an Fichte (Picea abies) mit antagonistischen Pilzen. II. Interaktionstest auf Holz. European Journal of Forest Pathology 14: 137–153.

Kallio, T. 1970. Aerial distribution of the root-rot fungus Fomes annosus (Fr.) Cooke in Finland. Acta Forestalia Fennica 107. 55 p.

Meredith, D.S. 1959. The infection of pine stumps by Fomes annosus and other fungi. Annals of Botany, London. 23: 455–476.

Redfern, D. 1989. Factors affecting infection of Sitka spruce stumps by Heterobasidion annosum and the implications for disease development. Proceedings of the Seventh International Conference on Root and Butt Rots. Canada. p. 297–307.

Rishbeth, J. 1951. Observations on the biology of Fomes annosus, with particular reference to East Anglian pine plantations. II. Spore production, stump infection and saprophytic activity in stumps. Annals of Botany, London. 15. 21 p.

— 1963. Stump protection against Fomes annosus. III. Inoculation with Peniophora gigantea. Annals of Applied Biology 52: 63–67.

Yde-Andersen, A. 1962. Seasonal incidence of stump infection in Norway spruce by air-borne Fomes annosus spores. Forest Science 8: 98–103.

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