Nursery Practices and Management of Fungal Diseases in Forest Nurseries in Finland. A Review

Arja Lilja, Sakari Lilja, Timo Kurkela and Risto Rikala

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The purpose of this article is to collate the literature on fungal diseases that occur on seedlings in forest nurseries. It describes the symptoms of the diseases, the infection pattern of each fungus and the possibilities of controlling the diseases. As background a short introduction is given on forests and nursery practices in Finland.

Keywords damping-off, root dieback, grey mould, Lophodermium needle cast, snow blights, Scleroderris canker, birch rust, pine twisting rust, stem lesions of birch, leaf lesions of birch

Authors' addresses *Lilja, Lilja* and *Kurkela*, Finnish Forest Research Institute, Vantaa Research Centre, P.O. Box 18, FIN-01301 Vantaa, Finland; *Rikala*, Finnish Forest Research Institute, Suonenjoki Research Station, FIN-77600 Suonenjoki, Finland **Fax** +358 9 857 2575 **E-mail** arja.lilja@metla.fi

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1 Introduction

1.1 Forests

The forests in Finland, situated between 60° and 70° N, form part of the boreal coniferous forest zone. In the southern part of the country the conditions are ideal for coniferous forest. On moving northwards the climate becomes cooler and more humid. One fifth of the forests is older than 100 years and one third older than 80 years. The proportions of the dominating tree species on forest land (20 mill. ha, annual increment at least 1 m^3 ha^{-1}) in Finland are: Scots pine (*Pinus sylvestris* L.) 65 %, Norway spruce (*Picea abies* Karst.) 26 % and broad-leaved species, mostly birch species (*Betula* spp.) 7 %. Pure stands, however, cover only 47 % of the forest land. The annual felling area is 2 % of forest land, clear fellings accounting for about one fourth of this figure (Statistical yearbook... 1996).

Prior to the 1960's natural regeneration was the prevailing forest reforestation method in Finland. During the 1960s, however, the annual planting area increased rapidly. It was 30 000 ha in 1960 and 81 000 ha in 1995 (Statistical yearbook... 1996). The total artificially regenerated area, seeded and planted in Finland is currently ca. five million hectares (Kukkonen and Rikala 1994). In 1995, 19 % of the regeneration area was seeded (32 000 ha), 48 % planted (81 000 ha) and 33 % naturally regenerated (57 100 ha) by the seed tree or shelter tree methods (Statistical yearbook... 1996).

During the 1980s, 210–250 million seedlings were produced annually in Finland. However, in the 1990s production fell to 150–180 mill. seedlings. The proportion of different tree species delivered for planting in 1995 was: Scots pine 44.3 %, Norway spruce 45.3 %, silver birch (*Betula pendula* Roth.) 7.9 %, downy birch (*B. pubescens* Ehrh.) 0.8 % and other tree species 1.7 %, the most import of which are larch (*Larix sibirica* Ledeb.), lodgepole pine (*Pinus contorta* Douglas ex Loudon), Carelian curly birch (*B. pendula* var. *carelica* (Merklin) Hämet-Ahti) and black spruce (*Picea mariana* (Miller) Britton, Strens & Poggenb.). The planting stock is produced by about 30 central nurseries (88 %) and about 70 smaller family-owned nurseries (12 %). The total area of the nurseries is 675 hectares, of which 37 hectares are plastic covered (Statistical yearbook... 1996).

1.2 Nursery Technology and Cultural Practices

Nursery technology and cultural practices have changed during the last two decades (Kukkonen and Rikala 1994). The use of abandoned agricultural lands and application of nutrients in the form of farm manure, compost and green manuring were mainly replaced by light sandy soils, peat and inorganic soluble fertilizers in the 1970's (Mikola 1957, Rikala and Westman 1979). In the open field, bareroot seedlings are usually fertilized with granular fertilizers, and container seedlings mainly with liquid fertilizers in the irrigation water. The need for fertilization in container production is determined by measuring the electric conductivity of press-water extracts from peat. Bareroot transplants are watered with moveable sprinkler systems, and container seedlings with mobile irrigation booms or fixed overhead sprinklers. The need for irrigating container trays is determined by weighing the container trays weekly, while in the transplanting field only visual and tactile estimation is used (Kukkonen and Rikala 1994).

Container seedling production has to a great extent replaced bareroot seedling production. Since the beginning of 1980's the proportion of container production increased from 29 % to 86 % (Yearbook of forest... 1980, Statistical yearbook... 1996). Bareroot seedlings are planted mainly in southern Finland. The most common types of bareroot stock for Scots pine are 2A+1A transplants (two growing seasons in the nursery field, then transplanted in the nursery field for one season) and container transplant "plug+1" (small container seedling retransplanted in the bareroot bed for an additional period of growth). For Norway spruce 2A+2A and 1M+2A (M = grown in a greenhouse) transplants and for silver birch 1M+1A and "plug+1/2"-transplants are the most widely used bareroot seedling types. The most common types of container for conifer seedlings are Eco/Paper pots, styrofoam pots (TAKO), although hard plastic containers seem to be becoming more common. In birch container seedling production, hard plastic containers (Plantek) and ecopots are most frequently used (Nursery statistics 1994).

Bareroot and container conifer seedlings are normally overwintered in the field under the snow cover. Only a few nurseries use cold storage. Both bareroot and container birch seedlings are usually lifted and heeled in light sand and left under the snow cover, or sacked in plastic or paper bags and moved to cold storage (–4 to –2 °C) in October for 6–8 months.

The quality of nursery seedlings in Finland is supervised by the Ministry of Agriculture and Forestry in accordance with the Forest Reproduction Material Trade Act of 1979 and the related Decision of 1992 (Decision of the Ministry... 1992). According to the Decision of Ministry, the seedlings to be sold should be healthy, vigorous and also in other respects suitable for the purpose in question. A seedling is not considered to meet the requirements if it has plant diseases or pests, or damage, caused by them which weaken its vigour, or it does not meet the requirements set for its size and the growing density, or the vitality or the structure of the seedling has such defects that the seedling is not suitable for planting. Furthermore, special seedling size standards have been issued for bareroot and container stock types by tree species. Three regional inspectors appointed by the ministry control seedling quality in the nurseries by carrying out supervisory surveys in the autumn and spring. The main idea of seedling inspection is to avoid the planting of diseased or otherwise low quality seedlings. In addition, the inspectors can advise the managers about how to sort out poor seedlings. Although the type of injuries or diseases in nurseries varies from year to year, economically significant damage does occur every year (Uotila 1995).

2 Diseases

2.1 Nursery and Diseases

In container production, the use of greenhouses with temperature regulation, selected growth substrate, irrigation and fertilization results in good seedling growth, but they may also favour the development of many biotic diseases (Landis 1984, 1989). Abiotic stress caused by environmental conditions or injury can also predispose a large number of rapidly growing seedlings to fungal attack (Landis 1984, 1989). Of course there is a relationship between the presence of the pathogen, host and suitable conditions for the pathogen, but in general there is always a risk of plant diseases in forest nurseries (Landis 1989). Manuals have been published for the identification and management of forest nursery diseases e.g. in Canada (Sutherland et al. 1989) and in the USA (Peterson and Smith 1975, Landis et al. 1989, Hamm et al. 1990).

The purpose of this article is to collate the literature on fungal diseases that occur on Scots pine, Norway spruce, and silver and downy birch in forest nurseries in Finland. The reviewed diseases also include root dieback of conifer seedlings, *Phytophthora cactorum* (Leb. & Cohn) Schr. as the causal agent of stem lesions on birch, and fungi causing birch leaf lesions; all diseases which have recently been reported to occur in forest nurseries.

2.2 Damping-off

Damping-off is a fungal disease that causes mortality during the first few weeks after germination. Pre-emergence damping-off is difficult to diagnose because the affected seeds are not visible. The soil- or seedborne fungi associated with the disease are not host-specific and they cause rapid decay and mortality of germinating seeds (Lilja 1979, Lilja et al. 1995) and emerged seedlings (Mikola 1952, 1953, Vaartaja 1952, Hanioja 1969). The classic symptom of post-emergence damping-off is decay of the hypocotyl at the ground level, but the point where infection starts is non-specific. In many cases there is no clear separation between post-emergence damping-off and root rot on young seedlings. Indeed, the same fungal species invading succulent seedling tissue can cause both damping-off and root rot (Sutherland and Davis 1991).

Species of *Pythium*, *Rhizoctonia, Phytophthora* and *Fusarium* cause damping-off throughout the world (Vaartaja and Cram 1956, Vaartaja 1967, Perrin and Sampagni 1986, Huang and Kuhlman 1990, Sutherland and Davis 1991). Other possible pathogens include species of *Cylindrocarpon, Cylindrocladium* and *Alternaria*, and *Botrytis cinerea* Pers. ex Nocca & Balb (Vaartaja 1952, Vaartaja et al. 1961, Magnani 1972, Darvas et al. 1978). In container nurseries, *Pythium* and *Fusarium* are the most common causes of damping-off (Sutherland and Davis 1991, James et al. 1991). Hanioja (1969) studied damping-off at the Punkaharju bareroot nursery in Finland. The only pathogenic species revealed by his experiments was *F. oxysporum* Schlecht., which attacked both Scots pine and Norway spruce. *F. oxysporum* Schlecht f. sp. *pini* (Hartig) Snyder & Hansen and *F. avenaceum* (Corda, Fr.) Sacc. isolated from seeds of Scots pine caused post-emergence damping-off in pathogenicity tests (Lilja et al. 1995).

Damping-off fungi can survive in seeds or in soil as mycelium or spores. They can be transmitted by seed, air, water or soil (Landis 1989). They become active and pathogenic when the environmental conditions such as temperature, relative humidity, soil moisture content or soil pH become favourable (Vaartaja 1952, Perrin and Sampagni 1986).

The best defence against damping-off and root rot fungi is effective integrated control; this includes hygiene, cultivation practices and chemical control. Not only must the equipment and tools used in cultivation be pathogen-free, but the containers and growing area surfaces should also be sterilized (Landis 1989). The risk of damping-off can also be reduced by using high-quality seed, the correct sowing density and sowing when temperature is high enough to promote rapid, even germination (Vaartaja 1952, Gibson 1956, Perrin and Sampagni 1986, Lilja et al. 1995). Wetness or high pH of the growth substrate favour damping-off and root rot (Landis 1989, Sutherland and Davis 1991). Where irrigation is used, it is important to avoid saturation of the soil (Heiskanen 1993, 1995). Fresh Sphagnum peat is commonly used in Finnish nurseries. It is a pathogen-free growth substrate and its pH is low enough to reduce losses. The fungicide thiram can be used as a seed treatment to control damping-off in Finland (Blomqvist et al. 1996).

2.3 Root Dieback

In the Nordic Countries, the problem of root rot of conifer seedlings was first recorded in Norway, and Galaaen and Venn (1979) named the disease 'root dieback'. In 1985, it was diagnosed for the first time in a Finnish nursery (Jalkanen 1985). It has been estimated that this disease results in a decrease of about 4 % in forest nursery production in Norway and in Sweden (Venn et al. 1986, Beyer-Ericson et al. 1991). In Finland, the economical losses have occasionally been high in some nurseries (Lilja 1996).

The symptoms of the disease on container or bareroot seedlings of both Scots pine and Norway spruce are discoloration of the needles, partial death of the root system and stunted growth. Several explanations for this disease have been proposed: fungi, nursery routines, indirect effects of pesticides and abiotic factors (e.g. temperature, drought or excess water) (Jalkanen 1985, Kohmann 1985, Venn 1985a, Unestam and Beyer-Ericson 1988). However, the patchy occurrence of damaged seedlings throughout the seedling beds is a feature suggesting that pathogens are involved in root dieback (Venn 1985a,b, Venn et al. 1986).

In Finland, as well as in Norway, the study of root dieback first concentrated on the whole mycoflora present on the roots of seedlings with symptoms and that on healthy seedlings (Galaaen and Venn 1979, Venn 1985b, Lilja et al. 1988, Lilja et al. 1992). The fungal flora associated with the roots of seedlings suffering from root dieback is rather similar in Norway and Finland (Galaaen and Venn 1979, Venn 1983a, Venn 1985 a,b, Lilja et al. 1992, Lilja 1994). The pathogenic fungal isolates include Pythiaceae and a *Rhizoctonia* sp. (Galaaen and Venn 1979, Venn et al. 1986, Lilja et al. 1992, Lilja 1994, Børja et al. 1995). Hietala et al. (1994) characterized the *Rhizoctonia* as a novel uninucleate type with a fruiting stage in *Ceratobasidium*. Hyphal anastomosis and RAPD analysis suggest that the uninucleate *Rhizoctonia* sp. is a homogeneous group and distinct from binucleate *Rhizoctonia*s (Lilja et al. 1996b).

It has long been known that *Rhizoctonia* species cause damping-off and root rot in forest nurseries (Vaartaja and Cram 1956, Saksena and Vaartaja 1961). Nursery inoculations by Venn et al. (1986) with a *Rhizoctonia* sp., which was later shown to be a uninucleate type (Hietala et al. 1994), reduced the growth of seedlings and resulted in typical root dieback symptoms (Venn et al. 1986). Similarly, infection reduced the root mass of both Scots pine and Norway spruce in greenhouse tests, producing stunted seedlings (Lilja 1994, Lilja et al. 1996b). In Hietala's studies (1995) all the infected Norway spruce seedlings remained alive, but the total root length was reduced compared to the controls.

In Swedish studies, the opportunistic pathogen, *Cylindrocarpon destructans* (Zins.) Scholt. and *Pythium* spp. were the most common fungi isolated from diseased roots (Unestam et al. 1989, Beyer-Ericson et al. 1991). A low light intensity and anaerobic root environment were found to predispose Scots pine roots to invasion by *C. destructans* (Unestam et al. 1989).

Lilja et al. (1992) found that none of the *Cylindrocarpon* spp. isolated from Finnish material was pathogenic. However, in the same study all the isolated Pythiaceous fungi were pathogenic to young, 2-week-old, Scots pine seedlings although only *P. ultimum* Trow. var. *ultimum* and *Phytophthora undulata* (H. E. Petersen) M. W. Dick. proved capable of killing older seedlings (Lilja 1994).

In Norway the most common fungus isolated by Galaaen and Venn (1979) from the roots of diseased Norway spruce seedlings was *P. sylvaticum* Campbell and Hendrix. In nursery inoculations with a *Pythium* species (later identified as *P. dimorphum* J. W. Hendrix & W. A. Campbell), some of the seedlings died suddenly after two weeks, but those that survived grew well (Venn et al. 1986).

P. dimorphum readily infects the roots of 10- to 12-day-old Norway spruce seedlings and causes the upper part, above the root hair zone, to became dark brown and the hypocotyl necrotic, while the root tips remained light coloured (Børja et al. 1995). In the study by Sharma et al. (1993), more than 30 different PR-proteins accumulated in the infected roots, and Børja et al. (1995) showed that the formation of lignin and the distribution of flavanols and condensed tannins were related to visual disease symptoms and cellular changes in root tissue.

The infection patterns of *P. dimorphum* and uninucleate *Rhizoctonia* sp. are different. Whereas, as described above, *P. dimorphum* does not infect root tips (Børja et al. 1995), infection by uninucleate *Rhizoctonia* sp. starts from the root tips (Hietala 1995). In an inoculation trial under sterile conditions, the root tips became pigmented and the infection resulted in a stunted root system. Hyphal aggregates typical of *Rhizoctonia* were observed on the surface of lateral root tips, but there were also hyphae inside cortical cells in the main root (Hietala 1995).

In general, *Pythium* spp. operate as a part of a disease complex involving other root pathogens that attack trees of all ages in nurseries (Hendrix and Campbell 1968, 1973). It has been hypothesised that root dieback is a disease of successive infections: primary infection by uninucleate *Rhizoctonia* sp. results in a high moisture content in the growth substrate, because the decayed roots of infected seedlings cannot take up water. Wet conditions favour Pythiaceous fungi and promote secondary attack by *Pythium* spp. (Lilja 1994).

In one recent study, both uninucleate *Rhizoctonia* sp. and *Pythium* sp. were isolated from roots of stunted, 1-year-old Scots pine seedlings in the spring. They also grew poorly during the second growing season, indicating that seedlings showing root dieback symptoms, even living and green ones, do not fully recover from the disease (Lilja 1994).

2.4 Grey Mould

Botrytis cinerea Pers. ex Nocca & Balb. infection, can be identified by the presence of greyish, cottony mycelia and spores on affected tissue. The fungus is a common saprophyte that is universally present in nurseries in the form of spores, mycelium or sclerotia (Gregory and Redfern 1987, Peterson et al. 1988, Sutherland and Davis 1991).

B. cinerea has been found on the seeds of many tree species including Norway spruce, Scots pine (Urosevic 1961, Kozlowska 1968) and silver birch (Lilja 1979). Mycelium in the seed may decay seed during storage (Mittal et al. 1987) or after sowing (Urosevic 1961, Kozlowska 1968). After sowing the fungus can spread from seed to seed in closely planted seedbeds (Baker and Smith 1966).

The fungus produces large numbers of spores which are spread by wind or greenhouse ventilation (Sutherland and Davis 1991). Fungus gnats (*Bradysia* spp.) as *B. cinerea* thrive in high moisture and they have been shown to disseminate grey mould spores (James et al. 1995). The spores germinate between 0 and 25 °C, with an optimum between 7 and 20 °C (Mittal et al. 1987). Canadian researchers have found that three hours at temperatures of around 15–20 °C and 98 % relative humidity is sufficient for infection if there is free water on plant surfaces (Russell 1990). Usually infection begins on the lower, weakened or dead parts of seedlings and then, if the conditions are favourable, subsequently spreads to adjacent healthy tissue (Lilja 1980, Sutherland and Davis 1991). It has been shown that grey mould fails to develop in black spruce (*Picea mariana* (Mill.) B. S. B.) seedlings with completely green foliage (Zhang 1992, Zhang and Sutton 1992). However, the disease was severe in black spruce seedlings subjected to a high temperature, 30–40 °C in darkness or drought (Zhang and Sutton 1994). Low light intensity is also an important predisposing factor (Zhang et al. 1995).

The disease often appears after abiotic damage, such as that caused by frost, fertilizers or herbicides (Sutherland and Davis 1991). *B. cinerea* has also been found to colonize necroses on Scots pine shoots caused by pine twisting rust. The secondary infection caused a fast expansion of shoot necrosis, untypical for *Melampsora* (Domanski and Kowalski 1988). It can also infect plants together with other fungi, for example a combination of *B. cinerea – Phomopsis* sp. occasionally kills new shoots of Douglas fir (*Pseudotsuga menziezii* (Mirb.) (Hansen and Hamm 1988).

Venn (1981) isolated *B. cinerea* from discoloured mouldy needles of Norway spruce seedlings in cold storage. Infections were found in lower, shaded branches and probably initiated in seedling beds (Venn 1979, Venn 1983b).

In Finland experience has shown that control of this pathogen is recommendable, especially in densely grown stands of Norway spruce, Scots pine and birches in greenhouses and outside during wet periods, because the fungus can cause considerable losses. It spreads rapidly via mycelia from seedling to seedling (Lilja 1980, 1986). If the seedling density is above 800–1000 m^2 in Scots pine beds then ideal conditions are created for major infection (Lilja 1986). It has also been isolated from stem lesions on silver birch seedlings (Lilja et al. 1996a).

Mittal et al. (1987) have published a comprehensive review of the literature on *Botrytis* spp. on trees, seedlings and seeds. They also analysed the possibilities of preventing and controlling the diseases caused by *Botrytis* spp. The most important control practice is to keep the microclimate within the canopy as dry and well aerated as possible by regulating the growing density, irrigation and ventilation in greenhouses. A number of fungicides have been recommended for the control of *B. cinerea.*, e.g. benomyl, thiophanate-methyl, thiram, dichlofluanil, tolyfluanid and vinclozolin (Blomqvist et al. 1996).

2.5 Lophodermium Needle Cast

The disease has previously been considered to be caused by *Lophodermium pinastri* (Schard. ex Hook) Chev. (Peace 1962), and in older reports, i.e. Costonis et al. (1970), the disease has been attributed to this fungus. Two biotypes of *L. pinasri,* differing in their pathogenicity and morphology, were recognised on Scots pine both in the plantation and in the nursery in Scotland (Millar and Watson 1971). Form A produced apothecia and black diaphragms on completely brown needles in the litter. In contrast, type B produced larger apothecia without diaphragms on the brown part of one-year-old needles whilst they were still attached to the tree (Millar and Watson 1971). Later Minter et al. (1978) showed that there are at least four *Lophodermium* species which can infect pine needles, and described Millar and Watson's form B as a new species *L. seditiosum* Minter, Staley & Millar.

Although Kurkela (1979) did not test the pathogenicity of *L. seditiosum*, which was the only *Lophodermium* species isolated from newly browned needles, he concluded that this fungus was the cause of needle cast epidemic of Scots pine in 1975 in Finland. Later inoculations made on Scots pine seedlings confirmed the pathogenicity of *L. seditiosum* (Diwani and Millar 1981, 1987). Development of symptoms, which started as yellow spots on needles, occurred only on inoculated seedlings (Diwani and Millar 1987). Later, 5 months after inoculation, needles turned brown and died, but the death and shedding of needles did not kill the plants although the new shoots were visibly weakened (Diwani and Millar 1987). Owing to the loss of healthy foliage, tree growth and quality were lower in outplanted infected trees than in healthy ones (Ostry and Nicholls 1989). *L. seditiosum* was found to be active in seedlings 1 year after planting out (Ostry and Nicholls 1989). In Finland diseased seedlings have occasionally been planted in the forest because in early spring, just after snow melt, diseased seedlings may still be green. The weakened seedlings have not tolerated the planting stress and have died (Lilja 1980).

L. seditiosum has been shown to infect green primary and secondary needles and only occasionally 2- or 3-year-old needles (Lazarev 1983).

Ascospores are the infecting propagules for this fungus (Minter 1981a,b, Lazarev 1981a). The occurrence of apothecia was found to be highest on younger primary needles and on 1-year-old secondary needles (Lazarev 1981b). Microtome sections from brown spots on green needles have shown that *L. seditiosum* colonizes epidermal, hyphodermal and mesophyll cells. Starch-free cells have been found in the mesophyll, and these cells were externally shown to form the yellow margin of the lesion (Diwani and Millar 1981). The contents of chlorophyll and carotenoid were 1.2–3.8 and 1.3–2.4 times lower, respectively, in infected than in visually healthy seedlings throughout the vegetation period (Savkina 1989).

High precipitation during late summer and fall creates conditions favourable for infection (Kurkela 1979, Diwani and Millar 1981). Germinating ascospores form germ tubes ending in appressorium-like structures (Diwani and Millar 1981, Karadzic 1989). Penetration by melanized appressoria directly through the cuticle and epidermis was observed (Staley 1975). Minter and Millar (1980) compared reports of the ascospore dispersal period, and concluded that different workers have trapped spores of different *Lophodermium* species. The dispersal of ascospores of *L. seditiosum* was been shown to start in June and reach its peak between September and October in Sweden (Fystro 1961), Estonia (Hanso 1968), Yugoslavia (Uscuplic 1981), Germany (Rack 1965) and the USA (Nicholls and Skilling 1974).

Lophodermium needle cast were among the first diseases to be controlled with fungicides in Finnish nurseries (Jamalainen 1956a). The first symptoms of the disease may be visible in September–October as small yellow and brown spots on the current year needles. The following spring the needles turn brown (Martinsson 1975, Kurkela 1994) and the apothecia do not develop until the following autumn (Kurkela 1994).

In general it is believed that the main source of *L. seditiosum* inoculum for infections in plantations and nearby nurseries is young, infected, fallen needles on which the ascocarps mature (Diwani and Millar 1990). According to Kurkela (1979), the abundance of *L. seditiosum* must vary considerably from year to year in Finland. The persistent populations of the fungus seem to be very low and ascospores may arrive from Central Europe or from Estonia where needlecast has proved to be more persistent (Hanso 1963). Severe epidemics occur only when the weather conditions are suitable for the pathogen (Kurkela 1979). However, the risk of economic losses with both bareroot and container Scots pine seedlings during an epidemic is so high that routine control with fungicides is considered to be necessary every year in the southern and central parts of Finland (Lilja 1986). A lower occurrence or absence of the fungus, together with climatic factors such as lower temperatures during autumn and earlier snow cover, may explain the lower risk of needlecast in the northern part of Finland (Kurkela 1979, 1994). In general the fungicide spraying times are consistent with the sporulation period of *L. seditiosum* (Minter and Millar 1980). In Finland spraying with fungicides such as maneb and chlorothalonil (Nicholls and Skilling 1974, Ostry and Nicholls 1989) should be carried out at 2-week intervals, from June to October (Lilja 1986).

2.6 Snow Blights

Snow blights of conifers are caused by *Phacidium infestans* P. Karst. and *Herpotrichia juniperi* (Duby) Petrak. *P. infestans* mainly infects pine needles although several other coniferous genera have been reported to be attacked (Björkman 1948, Kujala 1950, Roll-Hansen 1987). The fungus infects needles through the stomata in autumn, but symptoms do not appear until the following spring (Björkman 1948). In spring, affected Scots pine seedlings have a dirty green colour but soon turn brown and become light grey by late summer. It is also typical for diseased seedlings to occur in patches (Lilja 1986). *H. juniperi* sometimes infects needles of Norway spruce in nurseries, although it is of minor importance in Finland. The disease is also called brown felt blight or black snow mould. The fungus forms dense mats of brown-blackish mycelium on the lowest part of stems and needles of seedlings, often binding the needles together.

Snow blights usually occur in northern areas and at high altitudes in the south where there is sufficient snow to allow the mycelium to spread under the snow cover during winter (Jamalainen 1956b, 1961). However, in Estonia, where *H. juniperi* attacks Norway spruce in nurseries and dense forest stands, infection is not necessarily related to the depth of the snow cover: damage has been recorded up to a height of three meters in moist winter conditions in areas where only a few inches of snow covered the ground (Hanso and Tõrva 1975).

Production of ascospores by *P. infestans* in Finland has been shown to begin in September and to continue until either snow covers the apothecia or their spore production capacity is exhausted (Kurkela 1996). Free water is required to initiate Ascospores release. After the onset of rain, the number of spores reaches its maximum within 4–6 h, but heavy rain decreases spore liberation. Temperature does not affect spore release directly. Mature spores can be disseminated at a temperature just above zero, so that the fungus is capable of continuing spore release after frosts (Kurkela 1995a).

Ascospores which land on Scots pine germinate as soon as the needles become embedded in snow. In the laboratory, growth has been demonstrated at –5 °C (Björkman 1948) but the CO_2 concentration and activity of *P. infestans* under snow reach maxima at relatively high temperatures (–3 to 0 °C) in late winter when the mycelial colonies achieve their greatest extension (Vuorinen and Kurkela 1993).

The only effective control method for snow blights in nurseries is spraying with fungicides such as chlorothalonil and propiconazole. It is recommended that control spraying should be carried out as late as possible in the autumn, before formation of the snow cover. As the onset of winter can be unpredictable, treatment may have to be repeated a number of times.

2.7 Scleroderris Canker

Gremmeniella abietina (Lagerb.) Morelet var. *abietina* (Petrini et al. 1989), the causal agent of scleroderris canker of conifers, causes considerable damage in the Nordic countries by killing Scots pine and lodgepole pine (*Pinus contorta* Dougl. ex Loudon) stands (Kujala 1950, Roll-Hansen 1964, Roll-Hansen and Roll-Hansen 1973, Kurkela 1981, Karlman 1981, 1986, Barklund 1989, Sairanen 1990, Kaitera and Jalkanen 1992) and seedlings in forest nurseries (Jørstad 1925, Björkmann 1959, Kurkela 1967, Kurkela and Lilja 1984). The fungus also attacks Norway spruce, but Scots pine is more susceptible (Roll-Hansen and Roll-Hansen 1973, Skilling and Riemenschneider 1984, Barklund and Unestam 1988).

The pathogen is divided into North American, Asian and European races based on serology (Dorworth and Krywienczyk 1975), pectic isozymes (Lecours et al. 1994), ribosomal DNA restriction fragment length polymorphism (RFLPs) (Bernier et al. 1994), random amplified polymorphic DNA (RAPD) (Hamelin et al. 1993), random amplified microsatellites (RAMS) (Hantula and Müller 1996) and fatty acid (FAST) profiles (Müller and Uotila 1996). Hamelin et al. (1996) found using RAPD markers a third type: an alpine type within the European race.

Studies on the spore morphology of *G. abietina* in northern and southern Finland (Uotila 1983, 1990, 1992, 1993) and Sweden (Hellgren 1995) have revealed that there are two different types of *Gremmeniella* in the Nordic countries. These types have been named as A and B types or large (LTT) and small (STT) tree types, respectively. Analysis on DNA (Hellgren and Högberg 1995, Hamelin et al. 1996) and immunoblotting (Petäistö et al. 1996) supported the results of morphological studies. In northern Sweden these types have been shown to infect both Scots pine and lodgepole pine, so that there is a risk of *G. abietina* spreading from infected lodgepole plantations to Scots pine, and vice versa. This might indicate the lack of host specificity of the pathogen (Hansson et al. 1996).

Climatic conditions resulting in a long-lasting, deep snow cover favours the STT type and it is always found on small trees (Hellgren and Högberg 1995). The disease is typified by perennial cankers and shoot blights in those parts of the tree covered with snow during winter (Hellgren 1996). Another common feature in this type is the high abundance of apothecia (Uotila 1992). The LTT type infects larger trees and is characterised by damage to current-year shoots (Uotila 1992, Hellgren 1995). It is favoured by cool, cloudy and wet growing seasons and mild winters (Nevalainen and Uotila 1984, Karlman 1986, Uotila 1988, Karlman et al. 1994).

The European race of *G. abietina* also occurs in North America (Dorworth et al. 1977) and has been shown, on the basis of morphological, cultural and biochemical variables (Petrini et al. 1989) and RAPD markers, to be similar to the European LTT type (Hamelin et al. 1993). However, RAMS analysis revealed that isolates of the LTT type from North America, Italy and Iceland contained alleles not observed in isolates of the same type from Finland, Sweden and Norway (Hantula and Müller 1996). The disease symptoms caused by the North American race, in North America, resemble those caused by STT and the alpine type in Europe (Hellgren 1995, Hamelin et al. 1996). However, they are not genetically similar, the rDNA restriction and RAPD profiles indicating that the North American race was absent from the European samples (Hamelin et al 1996).

The fungus has a life cycle of 2–3 years were the asexual conidia are found the year after infection and ascocarps 2 years or later after infection. It spreads by means of conidia and ascospores. Inoculation trials have shown that most conidia germinate under and between the bracts on the base of the short shoots of *Pinus nigra* Arn. (Lang and Schütt 1974). However, bracts subtending the terminal buds can constitute another infection site (Siepmann 1976). Stomata on the surface of the bracts serve as the initial infection court for the fungus (Patton et al. 1984). *G. abietina* does not invade the host immediately after spore germination. After a number of weeks it spreads into peripheral tissues and then penetrates the periderm, from where it grows into the living shoot tissues by the end of the growing season (Lang and Schütt 1974, Siepmann 1976, Patton et al. 1984).

In nurseries, the first symptoms to develop in Scots pine seedlings are a change in needle colour to greyish-green, and drooping and shedding of needles. Later on, the needles turn brown, starting from the base (Kurkela and Lilja 1984, Barklund 1990, Hellgren 1995). The disease can also be detected at an early stage by pulling the needles since affected needles are easily detached (Petäistö and Repo 1988). All factors that retard shoot maturation decrease the resistance and increase the susceptibility to *G. abietina* infection (Donaubauer 1972, Uotila 1988). Increased nitrogen levels in the host have been shown to increase disease incidence and severity (Ylimartimo 1991, Barklund 1993). The damage is supposed to be connected with increased growth and incomplete lignification of the shoots (Ylimartimo 1993). Excess uptake of N will increase the contents of certain amino acids (Gezelius and Näsholm 1993), which have been demonstrated to increase growth of *G. abietina* (Ylimartimo 1993). However, a balanced nutrient status, assessed as the ratios of N to P, K and Mg, is perhaps the more important factor in resistance than the total content of N (Ylimartimo 1993). Low temperatures and low light intensity during the summer have also been found to increase *G. abietina* infection on young seedlings (Petäistö and Repo 1988).

Both LTT and STT types can infect Scots pine seedlings in nurseries (Uotila 1983), but inoculation of annual shoots resulted into disease so that 34.7 % of Scots pine seedlings sprayed with a conidia suspension of the LTT type were infected, while the corresponding value was 11 % in inoculations with conidia of the STT type (Uotila and Terho 1994). Similarly, inoculation of wounds on stems and shoots with mycelium of the LTT type resulted in larger necroses in the phloem than with mycelium of the STT type (Uotila and Terho 1994). Epidemics following cool, cloudy and wet growing seasons and mild winters are caused by the LTT type of *Gremmeniella* (Kurkela 1981, Sairanen 1990).

Infected Scots pine seedlings usually appear green and healthy immediately after the snow has melted. Development of the symptoms depends on the weather conditions and may take a number of weeks before damage becomes clearly visible. This can cause problems in the grading of seedlings for transplantation in the forest (Lilja 1986). Chlorothalonil (Skilling et al. 1984) or propiconazole (Blomqvist et al. 1996) is used in chemical control of the scleroderris canker.

2.8 Birch Rust

Birch-leaf rust is caused by *Melampsoridium betulinum* (Fr.) Kleb. The yellow, urediniospores appear in summer as pustules on the undersides of leaves. The fungus usually has its uredinial and telial stages on the leaves of *Betula* spp., although they sometimes also occur on the leaves of some *Alnus* spp. (Roll-Hansen and Roll-Hansen 1981). The aecial stage has been reported to develop on the needles of *Larix* sp. (Klebahn 1904). In Finland, inoculation trials with the basidiospores of *M. betulinum* have not been successful on *Larix* sp. (Liro 1906, Poteri unpublished). The fungus is capable of overwintering in buds or fallen leaves as uredinial mycelium (Liro 1906) or as urediniospores (Dooley 1984).

The results of Poteri (1992) suggest that *M. betulinum* has two *formae speciales*. In inoculation trials the urediniospores collected from silver birch (*B. pendula* Roth) and from downy birch (*B. pubescens* Ehrh.) hosts were, to some extent, specialized for their own host species; silver birch rust was more specialized in this regard. Downy birch, if inoculated with silver birch rust, showed partial resistance in the form of necrotic lesions at infection sites and reduced production of new urediniospores. Downy birch rust, by contrast, was compatible with both birch species and no hypersensitivity reactions were found even though several different clones of silver birch were tested (Poteri 1992, Poteri and Ryynänen 1994). However, so far only, a few isolations have been studied. Appressoria formation by germinating urediniospores and the location of appressoria on leaves have been studied by scanning electron microscopy in order to investigate the basis of the resistance. However, the lower infection level resulting from the combination of downy birch host and silver birch rust cannot be explained by failure of the latter to locate appressoria over stomata (Poteri and Ryynänen 1994). Silver birch clones were shown to have different resistance to silver birch rust, and all the tested clones grown at very low nitrogen levels were more resistant than those grown at high nitrogen (Poteri and Rousi 1996). Vigorous plant growth and density with a high nitrogen supply create higher moisture conditions on the leaf surfaces and thus favour urediniospore germination (Sharp et al. 1958).

The epidemic phase of *M. betulinium* rust occurs as the uredinal stage on birch in late summer. It is necessary to control birch rust in nurseries, because infection can seriously damage small seedlings and, in the case of taller plants, can cause growth reduction and mortality in the year after infection (Lilja 1973). The fungicide used is triadimefon (Blomqvist et al. 1996).

2.9 Pine Twisting Rust

The pine twisting rust, caused by *Melampsora pinitorqua* (Braun) Rostr, is a serious threat in Scots pine sapling stands in northern Europe (Kujala 1950, Roll-Hansen and Roll-Hansen 1966, Jalkanen and Kurkela 1984, Martinsson 1985), but also occurs in nurseries (Kurkela and Lilja 1984). The fungus may infect also several other pine species (Longo et al. 1974). Infected shoots may become girdled, and when the lesion is confined to one side of the shoot, normal growth on the opposite side results in bending of the shoot.

Several authors, including Gäumann (1959), Rostrup (1884), Hartig (1885) and Klebahn (1903), have described the life cycle of *M. pinitorqua*. Its alternate host is aspen (*Populus tremula* L.). The rust overwinters as the telial stage on dead aspen leaves on the ground. The microclimate during the winter may influence the condition of the teliospores. Teliospores on leaves collected in the fall did not germinate until early the next May and only if they were stored outdoors (von Weissenberg 1980). In nature teliospores germinate in spring after rain and produce basidiospores, which infect the current year's leading shoot of Scots pine. Kurkela (1973a) studied the dispersal of the basidiospores during June in three consecutive years and found that the maximum spore densities and total number of spores varied extremely between years. The results of field studies (Kurkela 1973a) were in agreement with those in laboratory experiments (Kurkela 1973b), i.e. the formation and release of basidiospores occurs over a wide temperature range from +0 to 27 °C (Desprez-Loustau 1986). The largest number of spores was recorded at temperatures of +15 to 20 °C (Kurkela 1973b). Rain has been shown to have a crucial influence on the formation and liberation of basidiospores, as well as infection (Klingström 1963, Kurkela 1973a). Spermogonia are produced by yellow-orange aecidia within 10–14 days of infection (Kurkela 1973a). The aecidiospores are spread by the wind and infect aspen, where the uredial and telial stages are produced on the underside of the leaves. The dispersal of aeciospores and urediniospores was shown to occur mainly during dry weather, although sudden rains briefly increased the spore density of aeciospores (Kurkela 1973a). In general, urediniospores are known to be released according to a diurnal rhythm (Taris 1966, 1968). In Kurkela's (1973a) study the diurnal periodicity of dispersal for both aecio- and urediniospore was obvious. There are several cycles of urediniospore production and infection on aspen, enabling the fungus to spread rapidly during late summer and early autumn (Kurkela 1973a).

The pine twisting rust resistance of pines is partly dependent on genetic factors (Klingström 1969, von Weissenberg 1973, Martinsson 1980). A wide range of compounds, such as resin acids, were extracted from the annual shoots of Scots pine and loblolly pine (*P. taeda* L.), that inhibited the germination of basidiospores, and these substances may be related to rust resistance (Klingström 1963, von Weissenberg 1973). Trees with a high growth rate were found to be more susceptible to the disease than those growing slower (Klingström 1969, Jalkanen and Kurkela 1984).

In general rust infections retard height growth. When Scots pine trees lost their leader shoot and formed a new one from a side branch, the immediate growth loss varied between 35–41% (Jalkanen and Kurkela 1984). In the absence of new damages the trees started to recover, but those trees with two subsequent leader changes the growth losses were severe, 35 % after the first and 63 % after the second leader change (Jalkanen and Kurkela 1984). The height of Scots pine that had corresponding infections after planting were 38 % lower after seven years than nonaffected pines (Martinsson 1985). The younger the plants, the higher is the risk that they will not survive after rust infection (Klingström 1963). Snow blight, Scleroderris cancer or grey mould are examples of diseases that may infect Scots pine after primary attack by pine twisting rust, and finally kill the seedlings (Martinsson 1985, Domanski and Kowalski 1988).

Disease incidence in nurseries is greatest near aspen. Elimination of aspen in the immediate vicinity of nurseries usually affords adequate disease control. The fungicide triadimefon is effective for chemical control (Desprez-Loustau et al. 1992).

2.10 Stem Lesions of Birch

A number of problems have appeared in connection with increased production of birch seedlings, the most serious of which, are stem lesions and cankers. Several fungi are known to cause these lesions. The most extensively studied in Finland is *Godronia multispora* J. W. Groves which infects seedlings in nurseries (Petäistö 1983, Rikala and Petäistö 1986) and is a common pathogen of natural birch saplings (Kurkela 1973c, 1974). Other fungi isolated from birch stem lesions in nurseries include *Fusarium avenaceum*, *Alternaria alternata* and *Botrytis cinerea* (Petäistö 1983, Lilja and Hietala 1994). *Plogwrightia virgultorum* (Fr.) Saccardo has also been found to cause lesions on young silver birch seedlings in clearcut areas (Kujala 1942).

F. avenaceum and *A. alternata* have also been isolated from necrotic tissue around the wound made by *Cicadella viridis* (L.) for oviposition (Juutinen et al. 1976) and from cankers on birch seedlings debarked by voles (Henttonen et al. 1994). The pathogenicity of *Godronia* spp. to birch has been known for a long time. *G. cassandrae* Peck f. sp. *betulicola* Groves causes cankers on many birch species, such as paper birch (*B. papyrifera* Marshall), gray birch (*B. populifolia* Marsh.) and yellow birch (*B. alleghaniensis* Britton) (Smerlis 1968, 1969, Desprez-Loustau and Dessureault 1987, 1988). *G. multispora* was found to be pathogenic to yellow (Martineau and Lavallee 1971), silver and downy birches (Kurkela 1973c, 1974, Romakkaniemi 1986). Inoculations with *G. fuliginosa* (Fr.) Seaver, isolated from diseased shoots of paper birch seedlings growing among willows, were successful on paper, gray and yellow birches. Pycnidia with characteristic spores of *G. fuliginosa* developed only on inoculated yellow birch seedling, other birch species had canker or lesions, but not pycnidia formation (Smerlis 1969).

Repeated defoliation by *Phyllobius* weevils was shown to weaken silver birch seedlings making them readily susceptible to *Godronia* infection (Annila 1979). Flooding was shown to delay phellogen restoration in the bark of silver birch but not in the bark of downy birch (Romakkaniemi and Poteri 1987). However, drought was shown to delay wound healing both in silver and downy birch (Romakkaniemi and Poteri 1987). This is in accordance with the results of Desprez-Loustau and Dessureault (1988), who showed that the disease symptoms of *G. cassandrae* infection increased as the water potential of yellow birch decreased. In the same way wounds on N-deficient yellow birch seedlings did not heal well, and deficiency of N increased seedling susceptibility (Desprez-Loustau and Dessureault 1988). On the other hand, high N fertilization levels in the previous year were found to increase stem lesions on birch stems in the following spring. Although, the number of *Godronia* infections did not increase in the seedlings. The increase of lesions was perhaps a result of a longer growing phase and delayed hardening, the seedlings were more susceptible for frost damages (Rikala and Petäistö 1986).

G. multispora infects silver birch more easily than downy birch growing on peatlands that are usually poor in nutrients (Kurkela 1973c, Romakkaniemi 1986). Fertilization with potassium decreased the disease incidence on peatland sites suffering from potassium deficient, but fertilization with phosphorus, on the other hand, increased the occurrence of the disease in the same area with phosphorus deficiency (Kurkela 1973c). In cases where nitrogen application was found to have an effect on the occurrence of stem lesions, it also increased *Godronia* infections (Kurkela 1973c). The widening of cankers caused by *Godronia* spp. occurs in the period of dormancy (Kurkela 1974, Desprez-Loustau and Dessureault 1987). During the growing season, seedlings were shown to prevent the disease spreading by producing secondary phellem around the dead tissue (Kurkela 1974).

In 1991, *Phytophthora cactorum* was isolated for the first time from necrotic stem lesions of silver birch seedlings in Finland (Lilja and Hietala 1994). In more recent studies, *P. cactorum* was isolated from 20–80 % of the diseased seedlings sampled from three nurseries. Inoculations of wounds on birch stems or leaf scars with this fungus resulted in necrotic lesions identical to those occurring naturally on birch seedlings in nurseries (Lilja 1996, Lilja et al. 1996a, Hantula et al. 1996). Most of the 2-month-old silver birch seedlings inoculated in spring died or broke already during the same summer, but older 1-year-old seedlings were still alive after the first summer (Lilja et al. 1996a, Hantula et al. 1996). However, in the case of older seedlings after a cessation of lesion enlargement during winter, further host invasion during the following summer resulted in the breakage of plants (Lilja et al. 1996a).

One way of controlling the disease is the practice of strict nursery hygiene. As the fungi responsible for stem lesions overwinter as resting structures in organic material, it is important to keep containers and growing areas clean (Landis 1989). It is also important to keep the microclimate within birch seedling stands as dry and well aerated as possible. Wounds, even small ones, increase the risk of stem lesions.

2.11 Leaf Lesions of Birch

The fungus *Taphrina betulae* (Fkl.) Johansson produces regular, round, pale green lesions up to 1 cm in diameter on the leaves of many birch species, including silver and downy birch (Mix 1949). The lesions can initially be distinguished only by the different shade of green from the healthy leaf surface. Later on they turn brown. The lesions are visible on both sides of the leaves. The fungus is common in nurseries and on young birches in the forest, but is apparently harmless.

Several species of Fungi Imperfecti are associated with lesions on birch leaves. Most of these fungi are Ascomycetes that overwinter on leaf litter. The first lesions, which produce conidia, usually appear in the beginning of July at the earliest. However, the connection with the teleomorphic fungi that occur on birch leaves in the spring seems to be unknown. According to Redlin (1995), *Gloeosporium betularum* (Ellis & G. Martin) von Arx is conspecific in the USA with a teleomorphic fungus belonging to the family Gnomoniaceae. *Gnomonia intermedia* Rehm occurs in Central Europe (Monod 1983) and also in Finland on birch leaf litter, but its hyphal cultures are different from the conidial isolations obtained from leaf lesions.

Common fungi sporulating on birch leaf lesions in Finland are *Asteroma* sp., *Gloeosporium* sp. or *Discula* sp., and *Marssonina betulae* (Lib.) Sacc (Kurkela 1994). *Gloeosporium* conidia germinate readily on agar to produce hyphal strands of several anastomosing parallel hyphae. In inoculation tests this fungus has produced leaf lesions. *Asteroma* conidia are produced on the same kind of lesions as *Gloeosporium,* but they are smaller than *Gloeosporium* conidia (Kurkela 1995b) and have not been induced to germinate on agar. It is possible that *Asteroma* is the microconidial form of *Gloeosporium. M. betulae* is easily distinguishable from these two on the basis of conidial morphology. It may have a teleomorph like *Drepanopeziza.* All three fungi occur both in nurseries and in open forest areas. *Asteroma* and *Gloeosporium* have been found only on leaf lesions, but *M. betulae* may also infect growing shoots.

Phomopsis sp., which infects birch leaves, has occasionally been observed on nursery seedlings. It is able to grow along the petioles into the growing shoot. The same type of *Phomopsis* has been found in Ontario, Canada, on the dying tops of yellow birch (Horner 1956), and its perfect stage was designated as *Diaporthe alleghaniensis* R. H. Arnold (Arnold 1967). Arnold (1970) expressed the view that the fungus could be a potentially serious pathogen for seedlings subjected to low light intensity and high humidity in their natural habitat.

3 General Conclusions

The same conditions, i.e. high densities, irrigation, fertilization, and herbicides, that makes nursery production of seedlings successful may also favour pathogenic fungi. Hygienic practices, the use of good quality seed, pest free growth substrate, sterilized containers and growing area surfaces, together with cultural practices such as proper irrigation, ventilation, fertilization, growing densities and removal of weeds all prevent the entry or survival of pathogens causing damping-off, grey mould, root dieback and perhaps stem lesions. Of course there are diseases such as Scleroderris canker, birch rust, snow blights and Lophodermium needle cast which need chemical control every summer. However, for environmental reasons the use of pesticides should be minimized and control sprayings only carried out at the correct time. A knowledge of the life cycles of pathogens and the conditions which predispose seedlings to diseases guarantees the right pest management. In Finland the autumn and even summer can be so wet that a cover on container fields, as used in some countries, might improve the quality of seedlings. It may be also difficult to sort out diseased seedlings in spring in the short time between lifting and planting. Diseased seedlings may appear green and healthy immediately after the snow has melted. The development of symptoms depends on the weather conditions and may take weeks before the symptoms of diseases such as Scleroderris cancer and Lophodermium needle cast become clearly visible. Thus we might need new tools, based on molecular biology, which provide the means to identify such diseases in seedlings.

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