SIROCOCCUS SHOOT BLIGHT OF FOREST NURSERY SEEDLINGS: A LITERATURE

REVIEW AND REPORT ON *PINUS CONTORTA* PROVENANCE TRIAL

by

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ABSTRACT

Sirococcus strobilinus Preuss causes a shoot blight of over 19 coniferous species in North America, Europe and Asia. The disease is particularly severe in British Columbia (B.C.) nurseries where it affects *Picea* spp. and *Pinus contorta* Doug. ex. Loud. and to a lesser extent *P. ponderosa* Laws and *Pseudotsuga menziesii* (Mirb.) Franco. The pathogen is seed-borne on *Picea* spp. and disseminated through rain and irrigation water. Optimum conditions for disease development are high humidity, low light intensity and mild temperatures. Some of these conditions prevail in B.C. nurseries, particularly since the introduction of container growing techniques. For example, most nurseries use frequent overhead irrigation and seedlings are grown in styroblock containers, the design of which contributes to the problem by providing a small volume of growing medium, which requires a high frequency of watering. Since high humidity appears to be the single most important environmental factor for infection of seedlings by *S. strobilinus*, its reduction through the use of sub-surface irrigation and/or by use of containers with a larger volume of growth medium should help alleviate the problem.

In an inoculation experiment 14 provenances of *P. contorta* varied in their susceptibility to *S. strobilinus*. Provenances from the Interior Wet Belt, Cascade Range and the Coast were more susceptible than were seedlings from the Dry Interior and the Sierra. Future research should be directed at determining heritability of the trait.

It is strongly recommended that the recently developed ELISA test using *S. strobilinus*-specific monoclonal antibodies be utilized by the B.C. Ministry of Forests to identify infected seedlots and that seeds carrying the disease be treated prior to sowing. Fungicide and heat treatments of the seeds have shown promising results despite germination and phytotoxicity problems. The registration of a non-phytotoxic seed fungicide (e.g. thiram) would be an incentive for nursery growers to treat diseased seedlots.

Currently, the principal method used in B.C. nurseries to control *Sirococcus* shoot blight is the application of chlorothalonil, mainly through the irrigation system. Research is needed to improve timing of applications and develop methods for optimum leaf coverage.

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CHAPTER I

INTRODUCTION

Sirococcus shoot blight, *Sirococcus strobilinus* Preuss (see table 1 for synonyms), affects over 19 coniferous species across northern North America (table 2), Europe and Asia. The disease is particularly severe on nursery seedlings and young regeneration where it can affect up to 75% of the trees (Grand and Jones 1980). In British Columbia (B.C.), the disease was first observed on western hemlock regeneration (Funk 1972); it later became a major cause of mortality on *Picea* and *Pinus* spp. in forest nurseries (Sutherland *et al.* 1982a).

In this Professional Paper the literature on *Sirococcus* shoot blight is reviewed and some of the causes for the prominence of this pathogen in nurseries are discussed. The first 5 chapters deal with the disease symptoms and damage, conditions for infection, source of inoculum and present control methods. An inoculation experiment comparing the susceptibility of *Pinus contorta* Dougl. ex. Loud. provenances to *Sirococcus* shoot blight is reported. In the general discussion, present control methods are examined and criticized and alternative stategies are discussed. The recommendations given in this paper are directed to nurseries of B.C.

CHAPTER II

SYMPTOMS AND DAMAGE

Description of _Sirococcus strobilinus_

On malt agar (MA) _S. strobilinus_ produces a low, felty-woolly, yellow-green slow-growing (0.7-1.6 mm/day at room temperature) aerial mycelium with even margin (Robak 1956; Funk 1972). The pycnidia are eustromatic, initially immersed, then strongly erumpent, separate, occasionally confluent, dark brown, globose and thick-walled; the hyaline, one-septate, fusiform conidia are borne on enteroblastic, determinate, integrated phialides (Sutton 1980) and released in a whitish cirrhus through the breakdown of the upper wall of the pycnidium. The size of pycnidia, conidiophores and conidia are 600×300 um^2, 50×2.5 um^2 and $12-16 \times 3$ um^2 (Sutton 1980), respectively.

Container-grown seedlings

In B.C. forest nurseries, _S. strobilinus_ is more prevalent on container-grown than on bareroot seedlings[1]. The disease develops on germinants and young seedlings in the spring and early summer causing symptoms that resemble late frost damage (Sutherland and Van Eerden 1980). The needles are killed from the base upward, then turn light to reddish brown and the dead seedlings remain upright. Small, irregularly rounded, light butterscotch-colored pycnidia, which later turn black, develop at the inner base of diseased needles (Sutherland and Van Eerden 1980). Generally, 1+0[2] trees are killed.

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[1] Container seedlings are grown in styroblock containers using an artificial medium (peat moss, vermiculite), whereas bareroot seedlings are grown in outdoor seedbeds in a similar fashion as agricultural row crops.

[2] The numbers refer to the years in the initial seedbed or container and the years in the transplant bed, respectively.

Bareroot seedlings

Symptoms usually appear in late summer through the fall and in the spring on 1+0 and 2+0 bareroot seedlings, respectively (Sutherland and Van Eerden 1980). On 2+0 trees only the current year tissues are affected. The fall symptoms may be confused with early frost damage. The pattern of symptom development, color of diseased tissues and presence of pycnidia are generally the same as for container seedlings. On bareroot seedlings, however, usually only part of the shoot terminal is killed and a lateral branch then becomes dominant, thereby causing stem deformity (Sutherland and Van Eerden 1980). Sometimes the tip of affected shoots assumes a crozier shape caused by a restriction in growth of the affected tissues (Smith 1973).

Forest trees

On mature trees, *S. strobilinus* attacks the current year's growth on the lower branches and the pathogen usually advances upward each year, reducing the live crown in the case of a severe infection (O'Brien 1973).

On the southern coast of Alaska, mortality occurred on 21% of the trees in a 16-year-old western hemlock, *Tsuga heterophylla* (Raf.)Sarg., regeneration (Wicker *et al*. 1978).

In Europe, *Sirococcus strobilinus* was isolated from 1-year-old shoots and needles of healthy and diseased European larch, *Larix decidua* Mill., and Arolla pine, *Pinus cembra* L. (H.K. Von Schnell, pers. comm.[3]). Microscopic analysis showed that the mycelium had invaded the phloem and the xylem tissues without causing any symptoms.

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[3]H.K. Von Schnell, Swiss Federal Laboratories for Materials Testing and Research. EMPA, Uberlandstrasse 129, CH-8600 Dubendorf.

Economic loss

Economic loss figures are not available for *Sirococcus* shoot blight. In commercial nurseries, the culling of diseased trees without identification of the causal agent makes it difficult to evaluate damage precisely. In B.C. container nurseries, the loss of 1+0 seedlings is taken into account at sowing and the economic losses to *Sirococcus* shoot blight are probably not as important as for 2+0 seedlings and regeneration trees for which intensive management through handling, pest control, fertilization, irrigation and storage has increased seedling value. Reports of up to 50% seedling mortality in nurseries and regeneration and up to 70% shoot mortality on 15 m tall red pines, *Pinus resinosa* Ait., in natural stands (Canadian Forestry Service) 1983 suggest that this disease has an economic impact on reforestation.

CHAPTER III

CONDITIONS FOR INFECTION

Optimum conditions for the infection of 6-month-old black spruce, *Picea mariana* (Mill.) B.S.P., are 16-21°C and a 16 h photoperiod under low light intensity (3200 lx). On MA, conidia germination occurred between 5 and 30°C and was most rapid (100% in 24 h) at 25°C (Wall and Magasi 1976). Others have found comparable germination temperature ranges, i.e. 10-30°C on water agar (Smith 1973) and 10-32°C on MA (Shahin and Claflin 1978). In both cases, germination was maximal at 15-20°C and was inhibited below 5°C and above 35°C. Although light did not affect germination of conidia or mycelial growth on MA, it was required for the production of pycnidia (Wall and Magasi 1976). A relative humidity at or near 100% for at least 1 day after and a dark treatment of seedlings prior to the inoculation were prerequisites for infection (Funk 1972; Smith 1973; Wall and Magasi 1976). Funk (1972) hypothesized that *Sirococcus* shoot blight is a low sugar disease and that the high susceptibility of western hemlock is related to its status as a shade tolerant forest tree. Further support to this hypothesis was provided by the study of the *Sirococcus* shoot blight outbreak in a 16-year-old western hemlock regeneration in Alaska referred to on p. 3, where the disease was causing a natural thinning in suppressed and intermediate crown class trees and thus was beneficial for management by enhancing the growth of dominant trees (Wicker *et al.* 1978). In the same study, the disease index for potential crop trees on a fertilized area was the highest of all areas examined. It was speculated that the high density of dominant and co-dominant trees created an environment favorable for infection and disease development.

Actively growing host tissues appear to be required for infection (Funk 1972). In a pathogenicity test, 3-year-old Colorado blue spruce, *Picea pungens* Engelm., were exposed to 10 ppm of gibberillic acid to increase host susceptibility (Shahin and Claflin 1978). One-year-old tissues are resistant to the pathogen but the age at which resistance is acquired is not known. Schwandt

(1981) suggested that 2+0 trees acquire resistance when they set buds.

Assuming that results from controlled environment chambers can be extrapolated to field conditions, the evidence indicates that cloudy weather accompanied by fog or rain and temperatures of 16 to 21°C for recurrent periods of 1-2 days during shoot elongation would favor the disease.

Field observations substantiate these results. In California, *Sirococcus* shoot blight was confined to two coastal nurseries where mild temperatures and summer fogs provide high humidity, while inland nurseries, which have a hot, dry growing season were disease-free (Smith 1973; Srago 1978). In the Maritime provinces, a *Sirococcus* shoot blight outbreak was associated with below average temperatures in June and July, the months of rapid shoot elongation (Wall and Magasi 1976). In B.C., the disease is particularly damaging in coastal nurseries where high humidity due to rain and fog during the growing season prevails (Sutherland *et al*. 1981).

CHAPTER IV

SOURCES OF INOCULUM

Sirococcus strobilinus is seed-borne on *Picea* spp. and 1-2% of the germinants in container nurseries may become diseased from this inoculum (Sutherland *et al.* 1981). Seeds with shrunken contents yielded the pathogen 7-9 times more often than seeds with normal-appearing contents. It was suggested that additional mortality in nurseries (up to 30%) is caused by secondary spread via conidia produced on diseased tissues and disseminated in rain and irrigation water (Sutherland and Van Eerden 1980). This inoculum is produced approximately 4-6 weeks after infection (Schwandt 1981). Apparently, the pathogen also spreads from infected to disease-free seeds prior to germination (Sutherland *et al.* 1981).

Sirococcus strobilinus was not seed-borne on serotinous[4] *P. contorta* (Sutherland *et al.* 1982b); it was suggested that the fungus is unable to reach the seeds in the tightly-closed cones. However, it is possible that the fungus is seed-borne on non-serotinous *P. contorta*. The fungus survived freezing temperatures (Wall and Magasi 1976) and overwintered on dead infected tissues (Schwandt 1981) providing inoculum for the following spring.

Infected trees and cones adjacent to nurseries and older residual overstory trees in young plantations might provide *S. strobilinus* inoculum for primary infection (Schwandt 1981). Srago (1978) found that inoculum for infection of non-native *Pinus* spp. came from the cones of Sitka spruce, *Picea sitchensis* (Bong.) Carr., trees adjacent to the nursery. The number of diseased pines was highest closest to the spruce. In natural stands of red pine, both mature trees and regeneration were affected but the disease was more severe on understory trees; it was suggested that overstory trees were the source of inoculum (Magasi 1975). However, it has been hypothesized that races of the fungus are host-specific. In an inoculation experiment an isolate of *S. strobilinus* from lodgepole pine caused infection in that species but not on spruce and hemlock

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[4]Cones that remain on the tree without opening for a year or more following maturation. The cones of interior provenances of lodgepole pine are usually serotinous while those of coastal provenances are non-serotinous.

(Murray 1961). O'Brien (1973) observed that understory white spruce, *Picea glauca* (Moench.)Voss., and black spruce remained disease-free while mature overstory red pine were affected. In a natural regeneration composed of 90% western hemlock and 10% Sitka spruce, more than 90% of the former were infected but the latter remained disease-free (Wicker *et al.* 1978).

It is generally accepted that conidia of *S. strobilinus* are water-disseminated (Peterson and Smith 1975; Sutherland and Van Eerden 1980). Infection appears to spread and intensify in the direction of the prevailing winds, suggesting that the conidia become air-borne (Schwandt 1981). Although no study of the long-distance dispersal of conidia of *S. strobilinus* is available, Tisserat and Kuntz (1983) showed that conidia of *S. clavigignenti-juglandacearum* Nair, Kostichka and Kuntz, which are similar in size and shape to conidia of *S. strobilinus*, become air-borne on aerosol drops and can survive up to 8 h in that state.

Shahin and Claflin (1978), commenting on the geographic separation of infection centres in Kansas (several of which were 320 km apart) concluded that the disease may have been introduced on infected nursery stock. However, they did not discuss the possibility that the fungus is indigenous to the central United States.

CHAPTER V

CONTROL

Present control of *Sirococcus* shoot blight is by: 1) chemicals, 2) sanitation and 3) manipulation of environmental conditions.

Chemical control

Lagerberg (1933) recommends using Bordeaux mixture to protect spruce seedlings against *S. strobilinus*. Tests for the control of *Sirococcus* shoot blight at the Humboldt Nursery in California showed that chlorothalonil, captafol, and zinc+maneb sprayed once every 2 weeks controlled the disease on 1-year-old Jeffrey pine, *Pinus jeffrei* Grev. and Balf., while copper and benzimidazole, and benomyl and thiabendazole were ineffective (Smith *et al*. 1972). Fungicides were applied 19 times throughout the year, including during the winter when no susceptible tissues were present. Since the appearance of the disease is synchronized with the start of new shoot growth it was suggested that fungicides should be applied only when susceptible tissues are present (Smith 1973) and when there is a reasonable expectation of cool, cloudy, humid conditions for more than 1 day (Wall and Magasi 1976). However, applications of chlorothalonil in Idaho nurseries failed to control the disease in early summer as cool rainy weather continued until July (Schwandt 1981), and new infections were observed in a B.C. nursery after captafol was applied in the early summer using the rates recommended by Smith *et al*. (1972) (Illingworth 1973). In B.C. the official recommendation for the control of *Sirococcus* shoot blight on forest nursery seedlings is three applications of chlorothalonil for container seedlings and one application for their bareroot counterparts (B.C. Nursery Production Guide 1986). The fungicide is usually applied via overhead spray boom. In nurseries with a previous history of *Sirococcus* shoot blight a preventive treatment is generally applied shortly after sowing.

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Seed treatment (seeds are dusted with a fungicide or have the fungicide added to the water used for stratification prior to sowing) is advised for seedlots with a history of *Sirococcus* shoot blight (Sutherland and Van Eerden 1980) but is rarely done in production nurseries.

Sanitation

Removal of diseased trees in 43-year-old and 30-year-old spruce plantations in Czechoslovakia (Ruzicka 1938) and of 1-year-old spruce seedlings in Sweden (Lagerberg 1933) is recommended for the control of *Sirococcus* shoot blight. The same practice is advised for B.C. nurseries (Sutherland and Van Eerden 1980). To reduce labor costs, Schwandt (1981) proposed removing diseased seedlings during weed removal. To prevent dislodging of infected needles, nursery workers were advised to cut the stems at the ground line instead of pulling diseased trees. The value of this practice on disease incidence has not been reported.

A method suggested to reduce the disease inoculum is to remove *S. strobilinus*-infected conifers nearby or in nurseries (Srago 1978; Schwandt 1981). The disease incidence was reduced by removing a large *S. strobilinus*-infected Sitka spruce near a pine nursery in California (Srago 1978).

Another recommended nursery practice is to sow seedlots with known disease history in a specific nursery area in order to confine the problem (Sutherland and Van Eerden 1980).

Detection of seed-borne inoculum

Seedlots used by B.C. nurseries are surveyed by the Canadian Forestry Service[5] for presence of *S. strobilinus* inoculum. Seed samples are surface-sterilized, incubated on MA and examined for presence of *S. strobilinus* mycelium. Results are usually obtained 2-3 wks after incubation and warnings are issued by the B.C. Ministry of Forests (B.C.M.F.) to nurseries for those seedlots

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[5] Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z-1M5

carrying *S. strobilinus*. It is recommended that those seedlots be watched closely for symptoms and when these appear, a fungicide should be applied to prevent spread of the pathogen (Sutherland and Van Eerden 1980).

Recently, monoclonal antibodies specific to *S. strobilinus* were prepared and used in an enzyme-linked immunosorbent assay (ELISA) to detect this pathogen in seed extracts (L. A. Mitchell, pers. comm.[6]). The method is highly sensitive and specific, allowing detection of as little as 25 ng of *S. strobilinus* antigen in extracts from 100 seeds. In addition, the test is rapid (results can be obtained within 24 h), economic, and can treat several different samples (96 on a single ELISA plate) at once.

Heat treatment

Heat treatment of *Picea* spp. seeds would help eliminate seed-borne *S. strobilinus* inoculum. In a test conducted by the Canadian Forest Service spruce seeds with previous history of *Sirococcus* shoot blight were soaked in water at 20, 47 and 49°C for 0, 30, 60 and 90 min, germinated and the seedlings monitored for presence of *S. strobilinus* (Rona Sturrock[7] unpublished data). The optimum temperature for seed germination and fungus death was 47°C. However, it was found that: 1) the rate of seed germination decreased with increasing temperatures and 2) the percentage of seed germination decreased with increasing exposure to heat treatment.

Manipulation of environmental conditions

Reducing the humidity and, in greenhouses, increasing temperature and illumination especially during periods of excessive cloudiness is recommended to prevent *S. strobilinus* outbreaks (Sutherland and Van Eerden 1980). Schwandt (1981) reported that daily overhead irrigation probably nullified the fungicide spray

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[6]Leslie A. Mitchell, Canadian Forestry Service, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z-1M5.

[7]Rona Sturrock, Canadian Forest Service, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z-1M5.

program in two Idaho nurseries and recommended that control efforts be aimed at minimizing the periods during which the foliage is wet. Seedlings should be thoroughly watered once a week instead of for short periods each day (Schwandt 1981). It was recommended that western hemlock be grown in greenhouses with a sub-surface irrigation system, forced-air ventilation and supplemental lighting to reduce *Sirococcus* shoot blight occurrence. Thinning of western hemlock regeneration was also proposed to create environments less favorable for the development of the disease (Wicker *et al*. 1978).

VARIATION IN THE SUSCEPTIBILITY OF *PINUS CONTORTA* PROVENANCES TO *SIROCOCCUS* SHOOT BLIGHT

Variation among western North American provenances in susceptibility to *Sirococcus* shoot blight was reported on 4-month-old lodgepole pine (Illingworth 1973). The plot was arranged in three randomized complete blocks and 0 to 25% disease variation was observed between replications of the affected provenances; the author suggested that the inoculum of the fungus may have not been evenly distributed throughout the experimental beds. Nevertheless, seedlings in adjacent beds varied in their susceptibility to the disease and it was inferred that variation in disease incidence among provenances is genetically-inherent (Illingworth 1973). Further support to this conclusion came from two Scottish nurseries where a lodgepole pine provenance from coastal Washington State was less susceptible than one from Interior British Columbia. In an inoculation experiment, these results were broadly confirmed, i.e. southern Interior B.C. provenances were more susceptible than those from central Interior B.C. and north coastal Oregon (Redfern 1974).

In regeneration forestry, there is strong interest in using provenances of *P. contorta* exhibiting resistance to diseases such as *Sirococcus* shoot blight; it is important to know if the trait exhibited by some of the provenances used by Illingworth (1973) is genetically-inherited or if other factors (e.g. tree phenology, environment) were responsible for the observed effect. The present experiment was designed to inoculate some of those provenances for which seeds were available and compare their susceptibility to *Sirococcus* shoot blight.

Materials and methods

Eighty seeds (limited amounts of seed were available) for each of 14 of the provenances used by Illingworth (1973) (table 3) were x-rayed and seeds with cracked seedcoats or shrunken contents were discarded while the remaining seeds

were stratified (soaked 48 h in water, drained and stored at 3°C for 2 weeks in sealed plastic bags), washed with cold distilled water for 3 h and germinated at 20-30°C and an 8 h photoperiod. Germination was low (5-43%) and the number of seedlings per provenance available for inoculation ranged from 4 to 35. The germinants were then sown individually in Walter's bullets[8] containing a 3:1 peat:vermiculite growing medium amended with 2.94 kg/m^3 dolomite lime and placed on metal trays (50 seedlings/tray). Seedlings were grown in a greenhouse, fertilized twice weekly with 10-52-11 soluble plant starter at 0.625 g/L for the first 3 week and then 20-20-20 at 1.15 g/L thereafter. Due to the failure to obtain sporulating cultures of S. strobilinus at the time of active shoot growth the seedlings were supplied with lighting from high-pressure sodium lamps to obtain a flush of new growth. Prior to inoculation, the 5-month-old seedlings were randomized and kept in the dark for 3 days. Only those seedlings with new growth were inoculated.

The S. strobilinus isolate used for inoculation was obtained from a 2+0 lodgepole pine seedling at the Red Rock nursery, Prince George, B.C. A spore suspension was prepared by flooding 4-week-old cultures of S. strobilinus, grown on 1.25% MA plates at 16-21°C and an 8 h photoperiod, with 5 mL of sterile distilled water and loosening the spores with the flamed end of a test tube. The suspension was then filtered through eight layers of cheesecloth, thoroughly mixed, and the concentration adjusted to 10^4 spores/mL. Two hundred mL of the spore suspension was sprayed on each of the six trays, with an aerosol sprayer, and the seedlings were enclosed in polyethylene plastic bags with extra-moisture and placed in a growth chamber at 16-21°C and a 16 h photoperiod at 2000-2500 lx. To ascertain that the inoculum was viable, one MA plate was sprayed with the spore suspension and incubated in the growth chamber; spore germination was checked after 48 h. Ten days after inoculation, the seedlings were taken out and examined twice weekly for disease symptoms. Diseased seedlings were placed in a moist chamber for 2 days to promote development of pycnidia. The conidia were examined under the microscope to confirm the

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[8]individual plastic tubes 22 cm^3 in volume.

presence of *S. strobilinus*. A Tukey-type multiple comparison test (Zar 1984, pp. 401–402) was used to compare proportions of diseased trees.

Results and discussion

Forty eight hours after inoculation, 100% spore germination was observed on MA plates, confirming the viability of conidia. *Sirococcus* shoot blight symptoms began developing on the seedlings 10 days after inoculation. Microscopic examination of the pycnidia confirmed the presence of *S. strobilinus* on all diseased seedlings. The percentages of diseased seedlings in the various provenances ranged from 14.3 to 70.8%. Provenances #72 from the Interior Wet Belt, #118 and #10 from the Coast, and #127, #120 and #156 from the Cascade Range were significantly ($p<0.05$) more susceptible than provenances #25 and #38 from the Dry Interior and #160 from the Sierra (Fig. 1).

These results confirm earlier findings (Illingworth 1973; Redfern 1974) that *P. contorta* provenances vary in their susceptibility to *S. strobilinus* and that there is a trend for higher susceptibility in the seedlings from the southern Interior of B.C. and Cascade Range origin than in the northern continental provenances.

Dry Interior provenances showed low susceptibility both in Illingworth's (1973) and in the present experiment. In the latter case optimum disease conditions and high inoculum level did not increase the incidence of *Sirococcus* shoot blight. The low susceptibility shown by provenances from the Dry Interior was not influenced by the change from Interior B.C. to greenhouse growing conditions; it is therefore suggested that this trait is at least partly under genetic control.

The sole Sierra provenance was less susceptible in the present study than in Illingworth's (1973) experiment. The small sample size may account for the difference.

Coastal provenances showed little susceptibility to the disease in previous work (Illingworth 1973; Redfern 1974). Also, it was reported that coastal

Figure 1: Percentage of 5-month-old *Pinus contorta* infected by
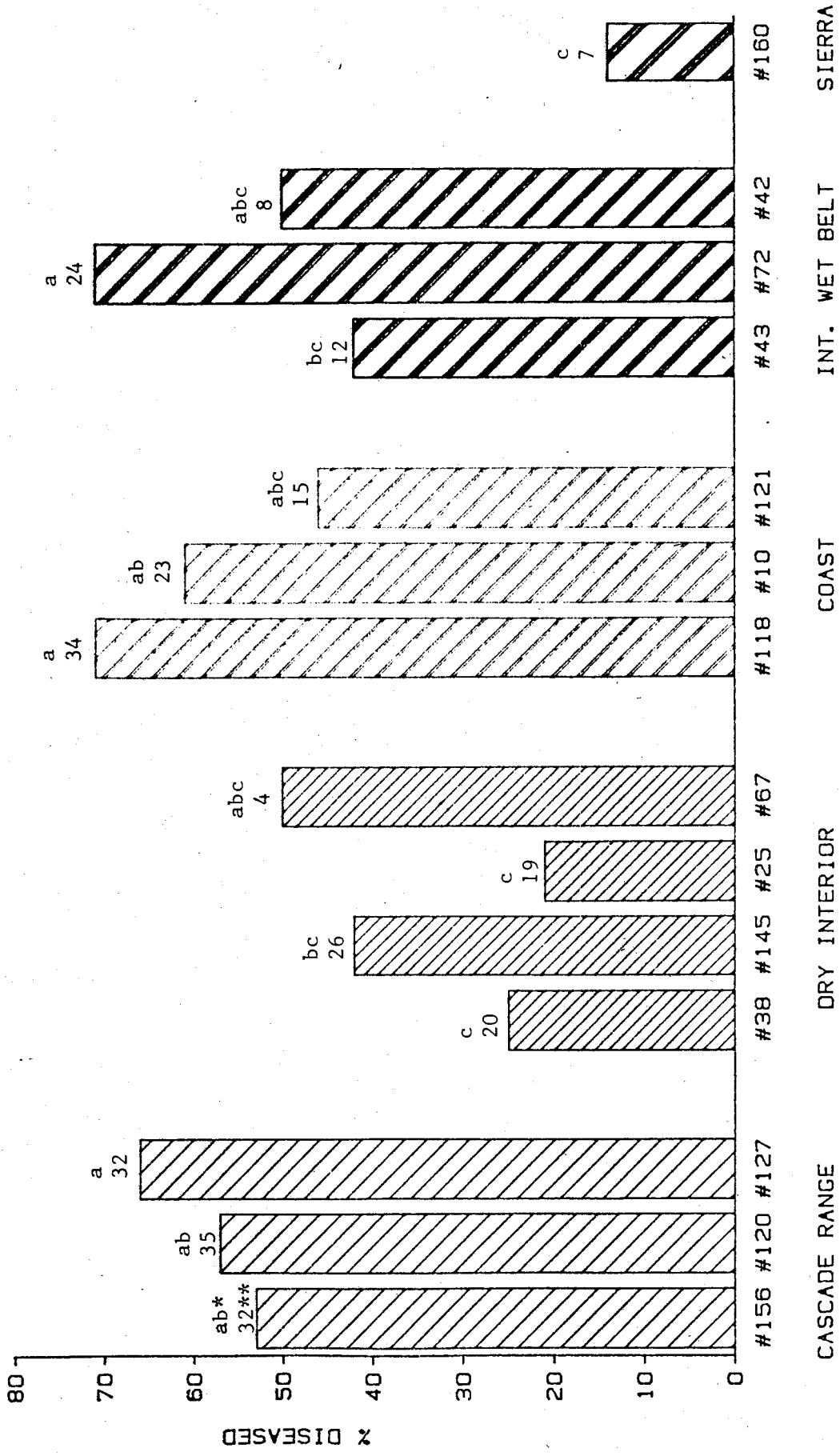*Sirococcus strobilinus*.

FIG 1

CASCADE RANGE   DRY INTERIOR   COAST   INT. WET BELT   SIERRA

%percentages topped with the same
 letters are not significantly different
 (p<0.05)

%%total number of trees inoculated

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provenances grown in the Prince George area (the site of Illingworth's 1985 experiment) exhibited low site adaptability (Ying *et al*. 1985). It is plausible that the low susceptibility observed by Illingworth (1973) for coastal provenances was mainly due to the absence of actively growing tissues. It can be speculated that the optimum growing conditions provided in the present experiment increased seedling growth over former experiments, therefore increasing the amount of susceptible tissue.

Since most provenances tested showing high site adaptability to environment from Interior B.C. (e.g. Interior Wet Belt, Cascade Range) (Ying *et al*. 1985) are also highly susceptible to *Sirococcus* shoot blight the disease could become increasingly important in the future since, from a sylvicultural point of view, those provenances are considered as high quality seed sources. It also suggests that there could be a correlation between the rate of growth of *P. contorta* and its susceptibility to *S. strobilinus*. This could mean that cultural practices such as fertilization will increase susceptibility to the pathogen. Wicker *et al*. (1978) observed such a phenomenon but attributed the increase in susceptibility to the thicker canopy which provided more shade and humidity.

Dry Interior provenances show both desirable site adaptability characteristics and low susceptibility to *S. strobilinus*. It would be of interest to determine the heritability of the latter trait and its stability under different environmental conditions.

CHAPTER VII

DISCUSSION

In this chapter I will discuss the merit of present control methods and propose alternative ways by which the disease could be reduced or prevented. Since it is difficult to evaluate the economic impact of *Sirococus* shoot blight on nursery production, it is also difficult to assess the economic feasibility of control methods. It is not my thrust to examine only those methods that are economically desirable since control strategies that are considered impractical in the present situation can become viable if a severe epidemic takes place.

Changing cultural practices

The literature suggests that the importance of *Sirococcus* shoot blight in British Columbia is linked to cultural practices used in forest nurseries. The conditions provided by nurseries (i.e. monoculture, dense sowing, frequent overhead irrigation, shading) are optimum for *S. strobilinus* outbreaks. Since the 1970's, an increasing number of seedlings are grown in containers (more than half of the 1985 production) and although this has resulted in a general decrease in soil-borne problems and damping-off there has been an increase in the incidence of shoot and foliar diseases such as *S. strobilinus* and the gray mold, *Botrytis cinera* (Fries) Persoon. In container nurseries, the small amount of soil available for water retention and the application of fertilizers via the irrigation system makes it necessary to water more frequently than in bareroot nurseries. In the following sections, I will discuss how changing cultural practices could decrease the incidence of *Sirococcus* shoot blight.

Greenhouses

In a greenhouse situation where the nurseryman has some direct control of environmental conditions, it should be possible to obtain reasonable control over *Sirococcus* shoot blight by manipulation of the environment. Temperature and illumination can be increased on cold and cloudy days through heating and adding

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artificial lights; this tactic would be particularly advantageous if it has the dual purpose of increasing the growth of seedlings and reducing disease incidence.

Reducing humidity is more difficult because of the high water requirement in the early stage of seedling development. The B.C.M.F. recommends frequent, low-volume misting from the time of sowing to the stage at which secondary needles are visible. Some nurseries find it necessary to water seedlings as often as every 30 minutes to facilitate seedcoat shedding. It was shown experimentally that seedlings inoculated at 60-70% relative humidity (RH) were not infected whereas infection occurred if seedlings were placed at 100% RH for as little as 24 h (Wall and Magasi 1976). Also, seedlings inoculated at 100% RH under sub-optimal temperature and illumination for disease suffered some infection. Humidity thus plays a major role in *Sirococcus* shoot blight outbreaks and increasing temperature and illumination alone will likely not bring control if humidity is not reduced.

Increasing ventilation will reduce air humidity to a certain extent but there will still be prolonged periods of leaf wetness during the susceptible stage, and therefore, it is unlikely that this measure will have a significant effect on disease suppression. Also, greenhouses are already equipped with ventilation systems and it is doubtful that such modifications would be economically appealing to nursery managers.

Replacing overhead by sub-surface irrigation would probably cause an important reduction in the incidence and spread of *Sirococcus* shoot blight. However, all forest nurseries in British Columbia use overhead irrigation systems. Changing to sub-surface irrigation would require major modifications of the present growing techniques. For example, styroblocks are designed for overhead watering; one way to overcome this difficulty would be to sit styroblocks on trays filled with water until the growing medium is water-saturated. Styroblocks should be anchored in order to prevent floating. Another way to provide sub-surface irrigation would be to redesign containers to incorporate irrigation pipes into the styroblocks or build containers with high edges and use

drip-irrigation systems. However, the major technological modifications and investments required would not likely be popular with nursery growers. Also, the use of sub-surface irrigation could potentially favor root pathogens.

At this point, it is important to study the impact of subsurface-irrigation on the incidence of *Sirococcus* shoot blight and to evaluate the effect of this system on occurrence of other pathogens such as *B. cinera* and root rot organisms. Although nursery managers would probably not be inclined to change their present system, it would be valuable to have an alternative to overhead irrigation when new facilities are being built. If overhead irrigation remains the only system used in B.C. nurseries, the rationale behind frequent watering should be revised and the growth and survival of young seedlings under less frequent and more thorough watering regimes should be investigated.

Outdoor-grown seedlings

For bareroot and container seedlings grown outdoors and in shadehouses, modification of environmental conditions is possible mainly through spacing and reducing or replacing overhead irrigation. Presently, the only containers recommended by the B.C.M.F. are the PSB 211 for lodgepole pine (882 seedlings/m^2), and PSB 313A (783 seedlings/m^2) for all other species. PSB 313 (639 seedlings/m^2) is also recommended for longer 2+0 rotations and PSB 415B (405 seedlings/m^2) is only recommended for larger stock. Spacing bareroot seedlings would probably have little effect on *Siroccocus* shoot blight incidence with regard to shading and aeration since the disease affects seedlings before canopy closure (i.e. before lighting and air circulation are decreased inside the canopy). However, the use of PSB 415B containers for all seedlings would likely reduce watering frequency because of the larger cavity volume (86.9 cm^3 as opposed to 49.7 and 53.8 cm^3 respectively for PSB 313A and PSB 313) thereby reducing humidity; the effect of this measure on the incidence of *S. strobilinus* should be studied. The greatest difficulty associated with the use of PSB 415B is that more space and more containers are required to grow the same number of seedlings as for PSB 313A and PSB 211, thus increasing the cost of production.

Unless the use of PBS 415B brings other advantages (e.g. lowered incidence of *B. cinera* or increased growth) it is unlikely that commercial growers would find it profitable to use low density containers.

Reducing irrigation or using sub-surface irrigation is not likely to have as important an effect in suppressing the disease on outdoor-grown seedlings as it would in greenhouses since seedlings would still be exposed to humid conditions provided by fog and rain. It might, however, be a contributing factor in reducing *Sirococcus* shoot blight incidence if other control methods are used.

Reducing the inoculum

Although it was shown that the removal of infected material reduced the incidence of *Sirococcus* shoot blight, more basic knowledge is needed to help evaluate this recommendation and make it more applicable. For example, it is important to know the host specificity of *S. strobilinus* inoculum. If it is found that the pathogen is host specific, growing seedlings outside of their distribution range (e.g. ponderosa pine in the Fraser valley) would provide protection against the disease. It would also mean that crop rotation for bareroot seedlings would be advisable to reduce the inoculum. Until now, the literature suggests that cross inoculation does occur, at least in some cases.

It would be helpful to know which species produce inoculum most abundantly. In one nursery report, Sitka spruce was reported as the main source of inoculum but it is not known if other conifers produce enough inoculum to justify their removal. In B.C., *S. strobilinus* has been reported on mature western hemlock and *Picea* spp. cones but only on seedlings of other conifers. It is possible that the main source of inoculum for the disease is mature spruce and western hemlock.

The number or concentration of conidia required to start an infection and the effective distance and means of dispersal of viable conidia are basic pieces of information that would help giving more specific recommendations, such as

the minimum distance that should be allowed between infected and healthy material or the maximum number of infected seeds that should be tolerated in diseased seedlots.

Detection of infected seedlots

Reducing seed–borne inoculum should be a major concern in preventing *Sirococcus* shoot blight outbreaks. The proper identification of suspected seedlots is therefore important. The detection method used at the present time is lengthy, time–consuming and insufficiently sensitive; it should be replaced by the more rapid and sensitive ELISA technique. Detection should be carried out as a routine on all seedlots handled by the B.C.M.F. Seed Centre, Surrey, B.C. Seedlots carrying *S. strobilinus* inoculum should be treated with a fungicide, sown individually (as opposed to the general practice of sowing many seeds per cavity) in an isolated nursery area and seedlings monitored closely for disease symptoms if environmental conditions are favorable to the disease. It would be of interest to correlate the results from ELISA tests with the severity of epidemics in these seedlots. If there is a significant correlation, this information could be quantified into a damage threshold above which the diseased seedlots should be discarded.

Fungicides

Presently, the method most commonly used to control *S. strobilinus* is the application of chlorothalonil. Some of the problems associated with this practice are the 1) cost of the treatment, 2) impossibility to "cure" diseased seedlings, 3) economics of registering fungicides for the relatively small market of forest nurseries, and 4) growing concerns of the general public, nursery workers and tree planters about health hazards and environmental damage associated with the use of pesticides. Some of the advantages are the: 1) rapidity with which the treatment can be applied after the problem appears, 2) compatibility of fungicide treatments with other recommended control methods, 3) possibility to confine an outbreak after its appearance and 4) treatment of infected seedlots.

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The treatment of seedlots carrying *S. strobilinus* inoculum should be encouraged. This measure is relatively inexpensive, protects seeds against damping-off organisms, and is not likely to cause public controversies because of its limited application and the small apparent impact it has on the environment. The application of chlorothalonil as a drench treatment after sowing or the incorporation of the fungicide in the stratification water would help alleviate some of the problems mentioned in the previous sections. It would also prevent the seed-to-seed spread of *S. strobilinus* prior to emergence and have the advantage of using small quantities of chemical. A serious drawback to this control strategy is the phytotoxicity of chlorothalonil to conifer germinants and the reduction of seed germination. The dosage response should be investigated. It is possible that lower doses would be toxic enough to prevent growth of the pathogen without affecting seed germination. Also, other fungicides could be screened for drench treatment such as thiram, a non-phytotoxic broad spectrum organic compound used as a seed treatment fungicide on a wide variety of crops.

When *Sirococcus* shoot blight symptoms appear and the disease develops around centers of infection, fungicides should be applied locally using a back-pack sprayer before the appearance of pycnidia, thereby preventing further spread and avoiding the treatment of the entire nursery. This type of rapid response implies the close monitoring of nurseries for early detection and the availability of trained personnel for identification of the pathogen. If practical, overhead irrigation should be reduced in treated seedbeds to reduce washing of the chemical from the foliage.

The efficiency of leaf coverage in nurseries using irrigation systems for fungicide application should be investigated. This research would be particularly important when chlorothalonil is applied as a preventive treatment.

Since only chlorothalonil is registered for use against *S. strobilinus* in B.C. nurseries there is a need to test other fungicides. Although there is no sign that the disease is developing resistance to chlorothalonil this possibility should be

considered. A rotation of fungicides would reduce the likelihood of such a situation occurring. Timing of application is a subject that needs better documentation. Recommendations for B.C. nurseries are to spray when the disease appears. However, if weather conditions are not conducive to *Sirococcus* shoot blight development, it might be desirable to delay treatment until favorable disease conditions prevail. Also, better knowledge of the period of susceptibility of the different host species is necessary when preventive treatment is done.

Heat treatment

The preliminary results reported herein indicate that heat treatment of conifer seeds has the potential to control seed-borne *S. strobilinus*. Nevertheless, both the reduction in the rate and percentage of germination are unacceptable drawbacks to this method. Future research should focus on reducing time of exposure to minimize seed damage.

CHAPTER VIII

CONCLUSION

In this Professional Paper I have reviewed several aspects of *Sirococcus* shoot blight of conifer nursery seedlings. The disease appears to be favored by some of the growing conditions provided in B.C. nurseries. Frequent overhead irrigation of container seedlings appears to be an important factor in the development of disease outbreaks. Future research should determine if different watering systems (e.g. subsurface) would significantly reduce disease occurrence. Also, the use of containers with larger soil volume should be evaluated with regard to reducing the required frequency of watering.

The epidemiology of *S. strobilinus* outbreaks is poorly documented; a better understanding of: 1) host specifity, 2) conidia dispersal and survival, and 3) number or concentration of conidia required for infection could lead to more specific recommendations.

It is known, however, that the pathogen is seed-borne on *Picea* spp. and more attention should be given to detection of infected seedlots and development of effective seed treatment. The ELISA technique should be implemented as a routine test at the B.C.M.F. Seed Centre and seed treatment fungicides (e.g. thiram) should be tested. Research on heat treatment of infected seeds should determine the potential for reducing seed damage.

Application of chlorothalonil is the most commonly used method to control *S. strobilinus* in B.C. nurseries; other fungicides should be screened for potential registration. The possibility for fungicide rotation should be considered to prevent the development of resistant strains of the fungus.

In an inoculation experiment, 5-month-old *P. contorta* provenances varied in their susceptibility to *S. strobilinus*. Provenances from the Dry Interior showed low susceptibility while seedlots from the Interior Wet Belt and the Cascade Range were highly susceptible, confirming previous results from Illingworth (1973). Future research should be directed at determining the heritability of this trait.

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APPENDIX

Table 1: Occurrence of *Sirococcus strobilinus* in North America

Species	Location	Reference
Larix laricina (Du Roi) K. Koch	Quebec	Canadian Forestry Service 1974
Libocedrus decurrens Torr.	British Columbia and Oregon	Shaw 1973
Picea abies Karst	North Carolina	Graves 1914
""	Quebec	Canadian Forestry Service 1970
P. engelmannii Parry	British Columbia	Sutherland et al. 1981
P. glauca (Moench) Voss.	Nova Scotia	Canadian Forestry Service 1975
""	British Columbia	Canadian Forestry Service 1976
""	Quebec	Canadian Forestry Service 1968
""	New Brunswick	Magasi and Wall 1975
P. glauca x *engelmannii*	British Columbia	Sutherland et al. 1981
P. mariana (Mill.) B.S.P.	Prince Edward Island	Magasi and Wall 1975
""	Newfoundland	Canadian Forestry Service 1984
P. pungens Engelm.	Ontario	Canadian Forestry Service 1973
""	Kansas	Shahin and Claflin 1978
""	North Carolina	Grand and Jones 1980
P. rubens Sarg.	North Carolina	Graves 1914
P. sitchensis (Bong.) Carr.	British Columbia	Sutherland et al.
Pinus albicaulis Engelm.	British Columbia	Shaw 1973
P. banksiana Lamb.	Ontario	Canadian Forestry Service 1974
P. contorta Dougl. var. *latifolia* Engelm.	British Columbia	Illingworth 1973
P. coulteri D. Don	Coastal California	Smith 1973
P. jeffreyi Grev. and Balf.	Coastal California	Smith 1973
P. lambertiana Dougl.	Coastal California	Smith 1973
P. ponderosa Laws.	North Idaho	Schwandt 1981
""	British Columbia	Canadian Forestry Service 1976
P. resinosa Ait.	Wisconsin and Minnesota	O'Brien 1973
""	Ontario	Canadian Forestry Service 1973
""	Nova Scotia	Canadian Forestry Service 1976
""	New Brunswick	Canadian Forestry Service 1982
Pseudotsuga menziesii (Mirb.) Franco	British Columbia	Funk 1981
Tsuga heterophylla (Raf.) Sarg.	British Columbia and Oregon	Funk 1972

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Table 2: **Synonyms** of *Sirococcus strobilinus* Preuss **(from Sutton 1980)**

Name	Reference
Sirococcus strobilinus Preuss	Linnaea 26:716 (1853)
Sporonema stobilinum Desm.	Ann. Sci. Nat., ser.3, 18:368 (1825)
Sirococcus strobilinus (Desm.) Petrak	Sydovia 1:155 (1947)
Plenodomus strobilinus (Desm.) Hohn.	Sber. Akad. Wiss. Wien 119:647 (1910)
Discella strobilina (Desm.) Died.	Krypt. Fl. Mk Brandenb. 9:752 (1915)
Ascochyta strobilina (cda) Wollenw.	Annls mycol. 15 :31 (1917)
Fusarium strobilinum Cda	Icon. fung. 1:4 (1837)
Phoma conigena Karst	Medd. Soc. Fauna Fl. fenn. 16:29 (1888)
Phoma conophila Sacc.	Syll. fung. 10:163 (1892)
Ascochyta conorum P. Henn.	Hedwigia 43:73 (1904)
Ascochyta piniperda Lindau	Nat. Pl. 1:368 (1900)

Table 3: **Provenances** of *Pinus contorta* **used for inoculation**

Number	Name	Region	Lat. N	Long. W	Elev. (ft)
10	Tofino, B.C.	Coast	40 05	125 47	50
118	Manzanita, Oregon		45 43	123 56	50
121	Pacific City, Oregon		45 14	123 57	50
145	Yellowstone Flats, Mont.	Dry Interior	45 30	110 45	7000
38	Fort Nelson, B.C.		58 32	122 42	1500
25	Hudson, Hope, B.C.		56 02	122 05	2380
67	Hinton, Alta		53 16	117 09	4000
72	Larch Hills, B.C.	Interior Wet Belt	50 42	119 11	2600
43	Kettle Valley		50 02	118 34	3700
42	Champion Lake, B.C.		49 11	117 35	3300
120	Mt. Hood, Oregon		45 18	121 45	4200
127	Chelmut, Oregon		43 19	121 39	5500
156	Quartz Pass, Oregon		42 18	120 47	5300
160	Camp Nelson, Calif.	Sierra	36 06	118 32	7100

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