ASSESSMENT AND CONTROL OF DOTHISTROMA NEEDLE BLIGHT

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ASSESSMENT AND CONTROL OF DOTHISTROMA NEEDLE-BLIGHT

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1. BACKGROUND

1.1 INTRODUCTION

The object of this handbook is to provide a source of reference and an introduction to the routine forestry practice of treating exotic pines against Dothistroma needle-blight. The information provided has been gained from over 30 years of research and experience in operational control of Dothistroma needle-blight. This handbook updates three previous versions, published in 1979, 1982, and 1988, and it is hoped that readers will find it a useful reference guide for running a successful Dothistroma control programme.

Dothistroma pini is a fungus that causes a needle cast of conifers. It was first noticed in New Zealand in the central North Island in 1962 and positively identified in 1964 (Gilmour 1967a). In our exotic forests the most important tree species which are significantly affected are *Pinus radiata, P. nigra* subsp*. laricio,* and *P. ponderosa.*

1.2 FIELD SYMPTOMS

- Brick-red bands appear on green needles and persist long after the green needles have withered and become dull brown or grey.
- The red zone is distinctly marked off from the rest of the needle.
- Small black spots (fruit bodies) erupt in the red infected band (Fig. 1).

Fig. 1: *Dothistroma pini* infection on *Pinus radiata* showing red banding with black fruit bodies.

The first symptoms are often found on the needles of branches near the ground. On current foliage of *P. radiata,* these symptoms usually first appear at the end of summer and become most obvious from about late June to early October. Some tree-to-tree variation in susceptibility to Dothistroma needle-blight can usually be seen, but infection levels are generally fairly evenly distributed within a stand (Fig. 2), unless the terrain differs significantly. In this, the distribution of Dothistroma needle-blight differs markedly from that of Cyclaneusma needle-cast. In stands affected by Cyclaneusma needle-cast, individual diseased trees are scattered among healthy trees. Defoliation by Dothistroma can occur all the year round but is most apparent between September and October. Defoliation and symptoms are least severe in early summer, as the newly flushed foliage is generally free of visible infection. On *P. nigra* and *P. ponderosa* symptoms of infection are at a maximum in November and early December. There can be some variation in this pattern in different parts of the country.

Fig. 2: A stand severely affected by *Dothistroma pini*. The photograph was taken in November.

1.3 TAXONOMY AND NOMENCLATURE

The binomial, *Dothistroma pini*, published by Hulbary (1941) based on material collected in Illinois, USA, has been generally accepted by forest pathologists as the correct name for the imperfect (or conidial) stage of the needle-blight fungus. Some authors regard *Dothistroma septosporum* (Doroguine) Morelet as having priority over *Dothistroma pini* Hulbary. The sexual stage of the fungus (*Mycosphaerella pini* Rostrup ex Monk) is not found in New Zealand.

1.4 SUSCEPTIBILITY OF CONIFER SPECIES TO DOTHISTROMA*

Very Highly Susceptible
Pinus attenuata

Highly Susceptible (at all ages)
Pinus nigra subsp*. laricio*, *P. ponderosa* in the central North Island; *P. jeffreyi.*

Highly Susceptible (but exhibit a high degree of resistance with age)
Pinus radiata — variable resistance after 15 years of age, depending on climate and micro-site.

Moderately Susceptible
Pinus pinaster, *P. canariensis*, *P. lambertiana*, *P. muricata* (blue strain) variable, but usually more resistant than P. *radiata,* exhibits resistance with age probably earlier than *P. radiata.*

Slightly Susceptible
Pinus contorta; P. elliottii; P. hartwegii; P. monticola; P. nigra subsp*. nigra.*

Slightly Susceptible (usually infected only when growing near other highly infected species)
Larix decidua, *Picea omorika*, *Picea sitchensis*, *Pseudotsuga menziesii*.

Very Slightly Susceptible
Pinus ayacahuite, *P. coulteri*, *P. michoacana*, *P. montezumae*, *P. patula*, *P. pseudostrobus*, *P. sabiniana*, *P. serotina*, *P. strobus*, *P. sylvestris*, *P. taeda*, *P. torreyana*.

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* Compiled from Forest Health Survey records, the Forest Health database, and Gilmour (1967b).

1.5 WORLD DISTRIBUTION

The first report of a serious outbreak of the needle blight was in 1957 from Tanzania (Gibson *et al.* 1964). By 1964, all major plantations in Tanzania, Kenya, Uganda, Malawi, and Zimbabwe were infected to some extent. In Europe, the fungus has been reported from United Kingdom, France, Spain, Portugal, Germany, Poland, Austria, Italy, Yugoslavia, and Georgia. It is a problem generally only in Spain (Gibson 1972), and in the late 1980s and early 1990s there was an upsurge in distribution and severity of the disease in France (Villebonne & Maugard

1999). Until the early 2000s Dothistroma was seen only very sporadically in the United Kingdom. Since then there has been an increase in infection, particularly in *Pinus nigra* plantations (Brown *et al*. 2003). In North America *Dothistroma pini* was found in several localities in central and eastern United States in the 1940s, mainly on *P. nigra* and *P. ponderosa* (Peterson 1967). It was first noticed in western and north-western United States and Canada in the 1960s on *P. ponderosa* and *P*. *contorta.* In the early 2000s recurrent severe outbreaks of Dothistroma needle-blight have been recorded in British Columbia on *P. contorta*. It is present in Mexico and Central America, and in South America in Argentina, Brazil, Chile, Colombia, Ecuador, Peru, and Uruguay. In Asia, it has been recorded from India, Nepal, Sri Lanka, Philippines, and Japan. It was first found in Australia in 1975 and is now present in New South Wales, Victoria, Australian Capital Territory, and Queensland.

1.6 NEW ZEALAND DISTRIBUTION

By the late 1960s *Dothistroma pini* had spread throughout most of the North Island. It was first discovered in Nelson in 1966, and had spread to Southland by the late 1970s. *Dothistroma pini* was first recorded in Canterbury in the early 1980s, and Otago Lakes and Mackenzie Country were the last regions to become infected in the late 1990s.

Although the fungus can be found in nearly all of the North Island, infection is generally low in forests north of Auckland (except for high-altitude areas in the centre of Northland), and in Hawke's Bay and Wairarapa. There is little or no discernible infection in coastal plantations on sand dunes. The central North Island, Waikato, and Taranaki are the most severely affected regions in the North Island. In the South Island, Westland is the most severely affected region. Nelson, Otago, Southland, and Marlborough north of the Wairau River generally have light infection. There are a few localised infected areas in Canterbury.

1.7 INFECTION PROCESS

Conidia (asexual spores) of *Dothistroma pini* are readily liberated from stromata (fruit bodies) into a film of water (Fig. 3.) They are dispersed by water splash, the dispersal distance normally being quite short. Infection in a stand is usually only from neighbour to neighbour and natural transport of spores over long distances is infrequent. Infected needles attached to the tree are the principal source of inoculum; when

Fig. 3: *Dothistroma pini* spores are dispersed by water-droplet splashes

needles drop to the forest floor, the fruit bodies are soon overgrown by saprophytes and spore production stops within 2 months (Gadgil 1970). Under favourable conditions (temperature 18°–20°C; needle surface moist), most spores landing on the surfaces of needles of susceptible hosts germinate within 3 days, the germ tubes continuing to grow on the needle surface and a very few (about 0.1%) forming appressoria over stomatal openings. An infection peg develops between the guard cells and a swollen vesicle forms just below the guard cells (Gadgil 1967). Further hyphal growth occurs in the mesophyll tissues if the needle surface is wet. Lateral spread of hyphae is limited to a few millimetres from the point of infection but a much greater length of the needle is killed through direct and indirect action of a toxic compound, dothistromin (Bassett *et al.* 1970) produced by the fungus (*see below* for more details on the effects of dothistromin).

The period from germination of spores to the formation of spore-bearing fruit bodies (the pre-reproduction period) varies from about 2 weeks to 6 months, depending on environmental conditions (Gadgil 1974).

1.8 EFFECT OF ENVIRONMENT ON INFECTION

1.8.1. Temperature and Moisture

When all combinations of four temperature regimes (day/night temperatures 24°/16°C, 20°/12°C, 16°/8°C, 12°/4°C) and four leaf-wetness periods (8, 24, 48 hours, and continuous moisture) were tested, it was found that most infection was obtained at 20°/12°C when continuous moisture was provided. The second highest rate of infection was provided by the 24°/16°C continuous-moisture treatment. At 16°/8°C and 12°/4°C there was less infection, regardless of leaf wetness period (Gadgil 1974). When the effect of moisture was further studied at 20°/12°C, it was found that infection occurred even when there was no additional moisture, but when this happened only a few needles became infected. There was an exponential increase in the severity of infection with increasing length of wetness periods (Gadgil 1977).

1.8.2 Light

Infection does not occur in the absence of light. The severity of infection increases linearly with increasing light intensity up to 200 W/m^2 (Gadgil & Holden 1976) (200 W/m^2 **=** about 25% of the midday light intensity at midsummer in Rotorua). This dependence of infection on light may explain why shaded branches do not usually become heavily infected.

1.8.3 Inoculum Density

Even under favourable conditions, very large numbers of spores are needed to get moderate levels of infection. For example, in one experiment it was found that a loading of 600 000 spores on the needle surfaces of a seedling resulted in only 18% of the needles becoming visibly infected.

An experiment was carried out in 1984 in which samples of needles were collected every month for 12 months and the numbers of spores produced on sample needles were counted. At the beginning of the experiment in April about 250 spores per needle were produced. Production peaked in June/July at about 4500 spores per needle and varied from 200 to 3500 spores per needle from November to February. The peak spore production in June/July was due to high numbers of fruit bodies per needle. There were fewer fruit bodies per needle over the warmer months as most of the heavily infected needles from the previous season had been cast. The high numbers of spores during winter is of little consequence as temperatures are generally too cool for infection to progress rapidly. The variation in spore production over summer was probably related to rainfall.

To summarise, although infection can occur over a wide temperature range and with very short leaf-wetness periods, it is only when you get optimum temperatures, long leaf-wetness periods, and heavy inoculum, that you get heavy infection.

1.8.4 Predicting Disease Levels

As stated above, severity of infection depends on temperature, leaf-wetness period, and inoculum density. A model to predict the Dothistroma spray programme has been developed by testing the effect of rainfall, raindays, and inoculum in the previous season on the percentage of susceptible area sprayed in individual years from 1966 to 2002 in two areas in the central North Island. For both data sets a multiple regression using average monthly rainfall from November to February (including October or March rainfall if 200 mm or more), total raindays of at least 0.1 mm from November to February, and the percentage of susceptible area sprayed in the previous season to predict area sprayed gave reasonable results. One data set gave an R^2 of 0.53 and the other gave an R^2 of 0.70. Some of the unexplained variation was attributable to incomplete or inaccurate data, management decisions influencing area sprayed, and, possibly, exceptional climatic events such as a wetter and warmer than average September or April. Forest companies can now benefit by being able to budget more accurately when estimating their spray programme. Details of the prediction model can be obtained from Forest Research.

1.8.5 Progress of the Disease

The usual progress of the disease on individual trees growing in the central North Island is as follows.

Very little or no infection occurs between May and August because of low temperatures. Many infected needles are shed and soon cease to be a source of inoculum. In September, as temperatures rise new infections occur from the infected needles that are left in the tree crowns, but their number is not large. At daily mean temperatures around 12°C, a development period of about 12 weeks elapses before fruit bodies begin to appear on newly infected needles. This can occur anywhere between early November and early December, depending on rainfall and temperature. Spores produced on these fruit bodies provide the inoculum for the first major infection. Temperatures in early summer are near-optimal for infection and if the weather is wet (as it usually is), there will be a large increase in disease level. Fruit bodies produced from November/December infections appear in February and a second cycle of infection may occur. The main infection period thus extends from November to the end of February in the central North Island; in warmer parts of New Zealand (e.g., Northland) it begins earlier (October to early November) and in cooler parts (e.g., Southland) it is a little later (December).

Spread of the disease within and between stands is limited. As stated in Section 1.7, the dispersal of spores is generally restricted to short distances. Consequently, a group of trees that are severely infected due to favourable conditions will not usually pose a risk to neighbouring stands. Infection becomes severe when environmental conditions are conducive to disease development, e.g., gully systems where needles remain moist for long periods, or highly stocked unpruned stands. Surrounding trees growing in conditions less favourable for disease development will not be affected to the same degree, despite their proximity to disease “hotspots”. Therefore, the cordon sanitaire approach of spraying a large buffer zone around “hotspots” is not justified on epidemiological grounds, although such spraying may be justified for logistical reasons, i.e., it may be cheaper to spray an entire stand than target spray many “hotspots” within a stand.

1.9 ECONOMIC IMPACT AND MITIGATION

Dothistroma needle-blight is one of the most serious diseases of *Pinus radiata* in New Zealand. Dothistroma has been present in many regions since the early to mid 1960s and the intensity of the disease has reached its maximum. Annual fluctuations of infection level are usually dependent on the weather during October through to March, according to the region. However, temperatures in Northland are probably too warm for the infection to develop quickly and this region is considered low risk. Otago experiences cool and dry conditions, Southland is cool and mostly dry, and Canterbury and most of Nelson are dry. Dothistroma needle-blight should not be a problem in these regions. The probable maximum hazard that can be expected for *P. radiata* is indicated in Fig. 4 (p.13) based on the premise that spraying is conducted when the average crown infection level in a stand reaches 25% or more. It should be noted that disease hazard may vary within the broad zones marked in Fig. 4 due to local topography or micro-site effect. The boundaries are

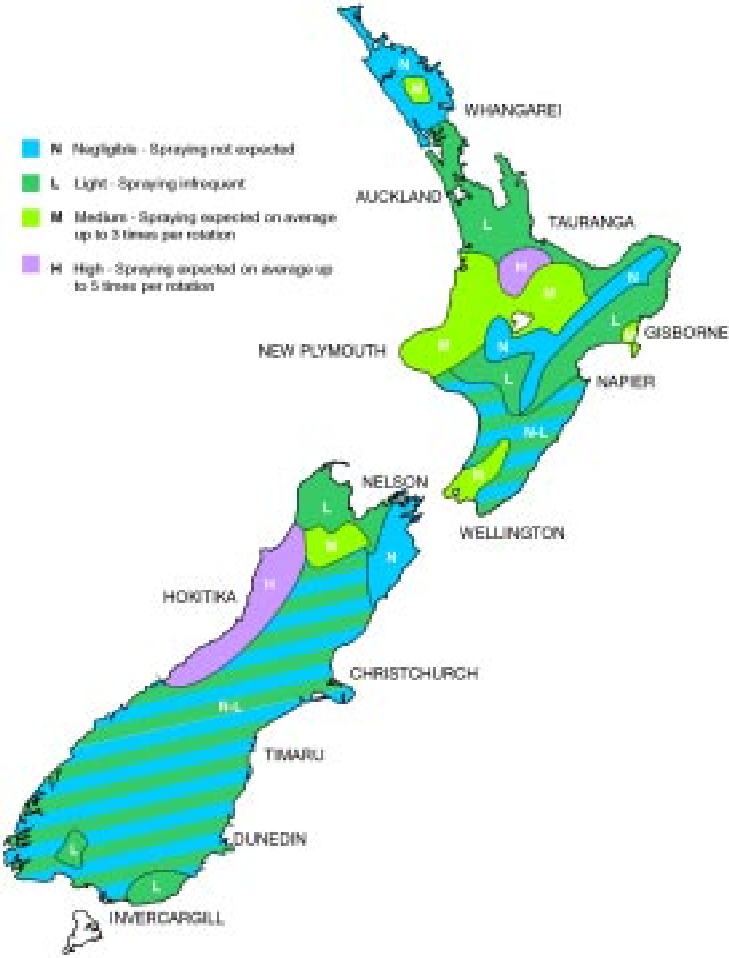

Fig. 4: Approximate boundaries for average disease hazard for 1- to 15-year-old *P. radiata* stands.

intended to indicate average risk within that zone. If detailed information is required for a specific plantation, the Dothistroma Control Committee may be able to help. In 1989 it was estimated that the total cost (control and growth loss) of the disease to the forest industry was $6.1 million per year (New 1989). More recent estimates of the annual cost approach $24 million (L.S.Bulman unpubl. data).

1.9.1 Increment Loss

The relationship between Dothistroma needle-blight and the growth of young *P. radiata* has been studied both in New Zealand (Whyte 1976; van der Pas 1981) and elsewhere (e.g., Gibson 1974). Whyte (1969) concluded that the impact on stands does not become significant until defoliation is greater than 25% of the current foliage in 50% of the total number of trees.

The establishment of a firm relationship between the disease and tree growth has been precluded by the complexity of the various factors involved, such as the variability of growth in young trees and widely fluctuating disease levels between seasons. Results from studies in the central part of the North Island (van der Pas 1981) relate growth losses to disease levels on an individual tree basis.

Over a period, i.e., at least 3 consecutive years, the reduction in volume increment is directly proportional to the average disease score over that period. For example, if an average of 40% of the crown is infected, there will be a 40% reduction in volume increment. Because infection is not uniform within a stand, however, it is much more difficult to get information on a crop basis. This is due to growth compensation where trees with low infection can take advantage of increased space made available by severely infected trees. Despite these difficulties, Woollons & Hayward (1984) have provided an estimate (*see* Section 1.9.4).

1.9.2 Effect of Spraying on Infection

The effectiveness of copper fungicide is due to two actions. Firstly, copper deposits on needles are slowly dissolved in water and this distributes copper ions over the needle surface. Spores released during periods of rain come into contact with the copper and are killed and don't germinate. Thus the foliage is protected from new infection. Secondly, copper stops fruit bodies producing and releasing spores. The second action appears to be most significant for control of the disease.

Therefore, the main aim of the chemical control programme is to reduce the amount of inoculum available at the beginning of the main infection period by killing as many spores as possible. Timing of the first (and often the only) treatment is crucial to the success of the spray programme (Gilmour & Noorderhaven 1971). Copper fungicide is very effective; germination of spores obtained from fruit bodies on needles was 74% before, and 1% after, a routine aerial spray application (P.D.Gadgil & L.S.Bulman unpubl. data). Gilmour (1981) demonstrated that the infection period starts in the central North Island in November. Applying spray just before the infection period starts will stop the release of spores from fruit bodies already present on needles and hence reduce inoculum available to infect healthy needles. It is not critical that new season's foliage is fully extended because the effectiveness of spraying results from reducing inoculum, and not solely from protecting new foliage.

1.9.3 Effect of Silviculture on Infection

Silviculture has several effects on disease levels following treatment. After thinning, the stand is opened which results in greater air circulation and the foliage dries at a faster rate than in an unthinned stand. This reduction in leaf wetness period slows the rate of infection. Thinning increases the distance between trees and this reduces the effectiveness of rain-splashed spores, most of which can travel only short distances. Highly susceptible small trees are removed in preference to less susceptible trees, thereby lowering the amount of inoculum available to continue the infection process. The removal of susceptible trees reduces the impact of the disease on overall stand volume.

Pruning removes infected foliage and lowers the inoculum available to initiate new infection. Foliage on the ground is rapidly colonised by other fungi and so infected needles produce spores for only a short period after pruning, and the spores that are produced are unlikely to travel from the ground to infect foliage on the tree.

1.9.4 Effect of Spraying on Increment

A Kaingaroa spraying trial in 13-year-old *P. radiata* indicated that final-crop trees sprayed on three occasions at the 25% prescription level will have an estimated 10 m^3/ha more volume at the end of the rotation than the final-crop trees in the unsprayed control area (van der Pas, Bulman & Horgan 1984). Gilmour *et al.* (1973) indicated that the best time to treat *P. radiata* for *Dothistroma* infection is when 25% of the unsuppressed green crown becomes diseased. This is the minimum level at which growth losses can be demonstrated on a stand basis. The recommendation was based on North Island growth rates and conditions. However, some companies have revised their criteria on when to spray and stands have been sprayed when infection levels were 15% or more. The economics of spraying lightly infected stands depend on wood volume saved by spraying, the spraying costs, and the price of wood (van der Pas, Bulman & Horgan 1984). For example, a stand with a rotation of 25 years that has been sprayed at ages 4, 5, and 6, assuming a 10% discount rate and spraying costs of $15/ha will give a discounted value of disease control of approximately $300/ha. In other words, the additional revenue needed to justify control is $300/ha. Woollons & Hayward (1984) found that spraying at the 25% level of green crown infection gave only marginal increment response. There was no difference in growth between sprayed and unsprayed treatments when the top 300 stems/ha in each treatment were compared. In four aerial spray trials differences in basal area between sprayed and unsprayed stands could be demonstrated only after 1 or more years of disease reduction; however, thinning eliminated basal area differences between treatments (van der Pas, Bulman & Horgan 1984). In a series of trials carried out in the mid 1980s to the early 1990s no growth differences between sprayed and unsprayed blocks could be shown after pruning and thinning (Bulman unpubl. data), but in heavily infected stands there is a case for spraying to reduce overall inoculum levels. In unthinned stands, or if the entire crop needs to be protected, growth response to spraying is likely and spraying may be justified.

1.9.5 Human Health Risk

In April 1984, the Minister of Forests advised of a possible human health risk from *Dothistroma* following tests in a Sydney laboratory which showed that dothistromin was capable of causing chromosome damage in mammalian cells. Consequently, the Dothistroma Control Committee recommended for the 1984/85 spray season that all stands of *P. radiata* where disease levels were 15% or more in which workers would be operating within 12 months should be sprayed.

The amount of dothistromin produced by different isolates varies, even within New Zealand where only one strain of the fungus exists. Strains from Germany and from the central United States have been shown to produce far greater amounts of the toxin than those from New Zealand (Bradshaw *et al*. 2000).

Dothistromin is a difuroanthraquinone having the same tetrahydro-2-hydroxy-bisfuran moiety as that of aflatoxin B1 produced by *Aspergillus flavus* (Gallagher & Hodges 1972). This particular structural feature of aflatoxin B1 is considered to be responsible for its hepatotoxicity and potential human carcinogenicity. Elliott *et al.* (1989) explored the possibility that dothistromin may be carcinogenic and thus pose a risk to forest workers. The amounts of dothistromin found in the forest environment (a maximum of 7 ng/ml in ponds and streams and lower concentrations in air and run-off from trees) were considerably lower than the minimum dose of aflatoxin (50 ng/kg body weight/day) needed to produce cancer in animals. They concluded that dothistromin was not a human health risk.

2. ASSESSMENT

2.1 ASSESSING INFECTION ON INDIVIDUAL TREES

The object of an assessment is to estimate the infection by *Dothistroma* of the tree crown. In a young plantation, before canopy closure, the **total** foliage of the tree contributes to tree growth and therefore should be assessed. In closed-canopy stands, only the **unsuppressed** part of the crown (the part of the crown above the canopy closure points) of a tree should be assessed. Usually, it is important to assess only current infection. Therefore, bare branches which have lost needles from past infection and other causes (i.e., Cyclaneusma needle-cast, or suppression) are ignored.

Assessment of severity of infection on individual trees is based on the observation that the fungus usually infects and causes defoliation of the lower part of the crown first. The proportion of infected to uninfected crown is then estimated and given as a percentage (refer to Fig. 5 for the assumptions involved in assessing pines for *Dothistroma* infection and defoliation).

Infection by *Dothistroma* on individual trees is assessed as a percentage of the total unsuppressed crown volume present on the tree that is diseased. Scoring is done in 5% steps, i.e., 5, 10, 15, 20, 25, etc. A score of 1% indicates that the disease is just detectable at a trace level. In areas where the disease is known to have been established for some years but is now only just detectable, a 1% score can be assumed. A score of 40% indicates that 40% of the foliage present is diseased. The comparative ability of all assessors should be tested at least once each year, prior to the survey. The aim is to maintain rating abilities within a variation of ±5% of the mean rating of all assessors.

The assessment method described is the method on which the national survey of infection levels is based, although there is a modification used for aerial survey. An evaluation of the accuracy of the assessment methods has been provided by van der Pas, Kimberley, & Kershaw (1984). More refined methods are sometimes used for assessing research trials, and Forest Research can provide further information on these if required.

Other technology is being developed to assess Dothistroma needle-blight from the air. There has been some success using hyperspectral remote sensing, specifically the CASI-2 camera (Coops *et al.* 2003).

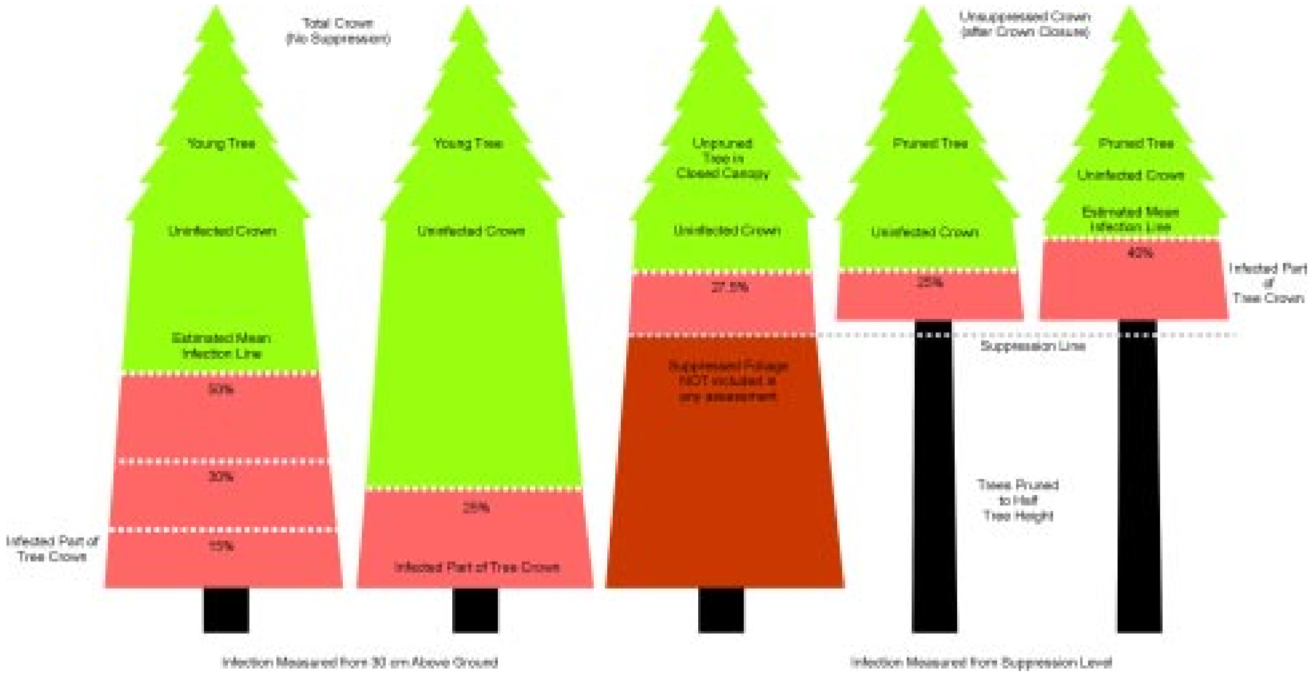

Fig. 5: Principles involved in assessing pines for *Dothistroma* infection (% to scale)

An accuracy of 70% was achieved for predicting three broad classes of Dothistroma damage on individual trees. Forest Research is currently evaluating this technology for use in New Zealand plantations.

2.2 SURVEY OF INFECTION

Assistance is available from local Forest Health Officers. Two organisations provide the majority of this service, Forest Health Dynamics* and Vigil Forest Health Advisory Services†. The annual survey of *P. radiata* is usually conducted between July and early August. Since the disease in many places may develop on *P. radiata* in September, it is possible that by October there can be visible infection increases of up to 10% on a July assessment figure.

Pinus radiata starts showing resistance to the disease once it is about l5 years old (later along the West Coast of the South Island and in parts of Nelson), but *P. nigra* and *P. ponderosa* are susceptible at any age. The survey of these species for infection should cover the following:

Pinus radiata (in July or August)

- All stands of susceptible age, i.e., trees 1–15 years old, possibly 1–20 years old for the West Coast of the South Island and parts of Nelson;
- All stands which were sprayed the previous year.

Pinus nigra and *P. ponderosa* (at the time the *P. radiata* survey is done)

- All infected stands, in areas where survey is customary.

Forest stands and woodlots may be left out of the survey if there is pre-survey knowledge that infection levels are low and there is no chance of a build-up to sprayable level by October. It should be noted that usually only areas of 2 ha or more will be included in the spray programme handled by the Dothistroma Control Committee (*see* Section 3.1) because increment gained by spraying is unlikely to exceed the excessive cost of spraying very small isolated blocks. However, the Committee will consider including small blocks if they are located near plantations that have been included in the spray programme.

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† Contact: Mark Self, Vigil Forest Health Advisory Services, Private Bag 3020, Rotorua. Ph 07 3435825.

2.3 SURVEY METHODS

The annual survey of infection levels should be conducted in all forests in which *Dothistroma* is present. The two survey methods that can be used are ground survey and aerial survey.

2.3.1 Ground Surveys

These are conducted by visiting stands and checking perimeters and accessible interior areas to determine the mean level of infection. For stands with up to 15% overall infection, only a general estimation is necessary after a tour through the stand. When in the assessor's opinion the level of infection is 15% or over, then there must be an assessment of 100–200 trees, usually along a transect line located to include an area of average condition for the stand. Alternatively, and when it is possible to walk through the stand, the assessment follows a transect through the longest axis of the area. The assessment data, plus the estimated area affected, age and height of the trees, and notes describing variations in infection are all entered on a survey form.

Ground surveys never give a complete coverage of a stand or forest, even if the areas can be viewed from vantage points. The only satisfactory means of assessing a total forest is from the air. Apart from being the only way to produce accurate results, for many regions it is the only way to complete the survey in the time available.

2.3.2 Aerial Surveys

These can be conducted from either a fixed-wing aircraft or (preferably) a helicopter. When assessing from the air in a fixed-wing aircraft, possibly flying at between 20 and 100 metres above tree tops and at about 80 knots (150 km/h), an assessor relies mainly on the colour of the infected foliage to determine disease level. Each stand assessed is rated with a percentage of infection by at least two assessors, one probably the local Forest Health Officer and the other a representative from forest management.

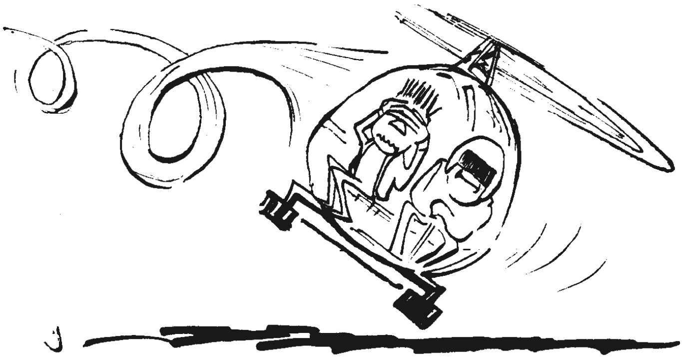
The technique of assessing from the air is a specialised one and requires experience. All certified Forest Health Survey Officers are tested for colour blindness to avoid the obvious problems that this condition would cause. There are sources of confusion and error, such as other defoliating agents, suppression, dead fern undergrowth, or dead or dying foliage on pruning and thinning debris. Because of this, stands rated at 15% or more from a fixed-wing aircraft are sometimes checked from the ground. Ground checks associated with fixed-wing aerial surveys are mainly quick inspections to confirm that the location, aerial rating, and area affected are correct.

A comprehensive flight plan should be made before any flight takes place. For farm forestry woodlots a 1:50 000 (N.Z.Mapping Series 260) topographical map is recommended for plotting the flight path from woodlot to woodlot. Forest maps, if possible indicating stands, species, and tree age, are required for each surveyed forest or woodlot.

The flight plan should indicate the sequence in which forests and their stands are to be flown. Before each flight the pilot should be familiarised with the flight plan.

An assessor must have some proven experience of scoring individual trees from the ground before attempting to give an overall assessment of a forest stand from the air. The ability to estimate mean levels of infection from the air is acquired from experience of visually rating the appearance of various crown levels of infection during ground surveys. From a fixed-wing aircraft the assessor views trees while travelling at speed, and has to make snap judgements of infection level based on foliage colour. Rating is done in 5% steps (as for ground surveys) but the rating represents the average for the area. If there is a variation in infection levels over different parts of a stand then these parts should be given individual ratings. Giving individual ratings to different parts of stands is especially desirable when this information can be used for spraying, e.g., a gully (which is liable to be more heavily infected than its surrounds) is an identifiable unit for spraying. Both the assessors in the aircraft should agree on a rating before moving on to the next stand. Ratings should be noted in a flight logbook or on a forest stand map by both assessors. One of the assessors can use a tape recorder if he or she wishes.

Helicopters are preferred for surveying Dothistroma needle-blight levels because, although the cost is greater, assessing accuracy is improved to the point that ground checks are not required. They are best used for larger forests, or where the distance between forests is small. With helicopter flying, assessors are not subject to the risk of airsickness whereas the rigours of flying in a fixed-wing aircraft at low level preclude many people from taking part. If your staff suffer from airsickness there is often no alternative but to use a helicopter.



… Helicopters are preferred …

2.4 REPORTING

A report of the survey results should be compiled and made available to the forest manager or their representative for use in making up a schedule of areas to be sprayed.

Note: A 12-minute video which describes the ground and aerial assessment techniques and survey procedures is available from Publications, Forest Research, Private Bag 3020, Rotorua, at a cost of $82.50 (incl. GST).

3. TREATMENT OF PLANTATIONS

3.1 THE DOTHISTROMA CONTROL COMMITTEE

In 1966 it was realised that Dothistroma needle-blight was of national significance, and that many of our exotic pine plantations were at risk. It was considered that to achieve effective treatment of the disease it would be more efficient to conduct control operations on a co-operative basis. To this end, major forest owners came together to form a representative group — the Dothistroma Action Committee (Gilmour *et al.* 1973). The Committee, since renamed the Dothistroma Control Committee, is responsible to and reports to the Forest Owners' Association. The main functions of the Dothistroma Control Committee are to:

(1) Purchase bulk lots of copper fungicide at competitive rates on the world market;

(2) Purchase bulk lots of spraying oil on the New Zealand market;

(3) Organise and let contracts for the aerial application of the fungicide;

(4) Monitor the quality of the fungicide;

(5) Review any new techniques or developments from research;

(6) Advise forest owners of the actions taken by the Committee on their behalf.

The Committee comprises representatives from the New Zealand Forest Owners' Association, Ministry of Agriculture and Forestry, Forest Research, and the Farm Forestry Association. The Secretary of the Dothistroma Control Committee can be contacted at the following address:

Dothistroma Control Committee
P. O. Box 1035
Rotorua.
Ph (07) 332-3454

3.2 CHEMICALS USED TO CONTROL DOTHISTROMA INFECTION

Research trials have shown that copper fungicides are extremely effective in controlling *Dothistroma pini* in New Zealand. Over the years, both cuprous oxide and copper oxychloride have been used in operational spraying. Both fungicides were equally effective in controlling the disease, but as cuprous oxide was more expensive only copper oxychloride was used from 1972 to 1997. Since 1997 the use of copper oxychloride has declined. The main reason for the switch was again price — cuprous oxide is delivered in the form of a 75% wettable power which results in lower handling and application costs. The suppliers of cuprous oxide also offered more competitive tender prices from the late 1990s. Initially, some concerns were expressed that the dust from cuprous oxide caused some workers to feel unwell. For the 2001/02 season a de-dusted cuprous oxide formulation was supplied and feedback indicated that both copper oxychloride and de-dusted cuprous oxide caused no problems. During the 2002/03 season only cuprous oxide was used.

The fungicide is supplied as a wettable powder formulation and hence contains substances which enable it to mix readily with water, and which also help to maintain the finely ground fungicide particles in suspension.

As up to 200 tonnes of fungicide have been used in any one year, tenders are called world wide for the annual supply of copper fungicide. Tenderers are required to supply a sample of their product which is tested for copper and lead content, corrosiveness, and its ability to remain in suspension both before and after accelerated storage tests. After delivery, further samples are again taken and tested to ensure that the fungicide meets the required standard. This testing programme ensures that any problems encountered are not due to the quality of the fungicide. Prior to the 2003/04 season the permitted level of lead contamination in copper was 250 ppm. This level had been retained even after the 75% copper product (cuprous oxide) was used. This in effect amounted to a significant reduction in allowable lead contamination on a per kilo or per hectare basis when compared with a 50% copper product. As most of the product used in the previous few years had lead levels well below the 250 ppm limit, the Dothistroma Control Committee revised the 250 ppm level to a lower one, as part of a process of continuous improvement, and a process of improving environmental performance. The Dothistroma Control Committee agreed that for the 2003/04 tender, the level of lead contamination would be set at no greater than 150 ppm.

From 1966 to 1981, 4.16 kg 50% copper in 50 litres of water was applied per hectare. From 1982 to 1984 this was reduced to 4.16 kg 50% copper in 20 litres of water/ha. As a result of improved spray technology and research, in 1984 the application rate was reduced to 1.14 kg 75% copper, or 1.66 kg 50% copper, in 2 litres of oil made up to 5 litres with water, per hectare.

Since the introduction of the 5 litres/ha spray application rate in 1984, an emulsifiable spray oil has been added to the spray mix. This is added to reduce the evaporation of the fine spray droplets and also because it has been shown that the spray oil enhances the effectiveness of the fungicide in controlling the disease.

3.3 TIME OF YEAR TO SPRAY

Trials have been conducted in different parts of the country to determine the optimum time to spray *P. radiata* against Dothistroma (e.g., Gilmour & Noorderhaven 1971; Gilmour 1981). They indicated that the optimum time could vary by a few weeks from year to year, probably because of the weather. Generally, the best time for a single spray application is between October and November. The spray should be applied just before infected needles that were carried over from the previous season are ready to produce and release spores in quantity. This occurs after periods of rain when average daily temperatures reach about 16°C. Therefore the first spray should be done earlier in warmer regions. If a second spray application is required, then it is best applied between January and the beginning of February, about 2 to 3 months after the first spray was applied. The recommended application times for different regions are given in Fig. 6 (on p.27). These are general recommendations based on average climatic conditions within each zone. Conditions that influence the time to spray may vary between individual forests. Information regarding when to spray may be obtained from the Dothistroma Control Committee or Forest Research.

3.4 NOTIFICATION OF AREAS TO BE SPRAYED

To enable flying contracts to be let in time for the October application, the areas to be sprayed have to be known by mid-August. For administrative convenience, the South Island spray programme is organised locally, with the Dothistroma Control Committee supplying the chemicals. For the North Island, notification of areas to be sprayed, accompanied by a forest map indicating exact location and boundaries of spray areas, must be supplied to the Secretary of the Dothistroma Control Committee by mid-August each year.

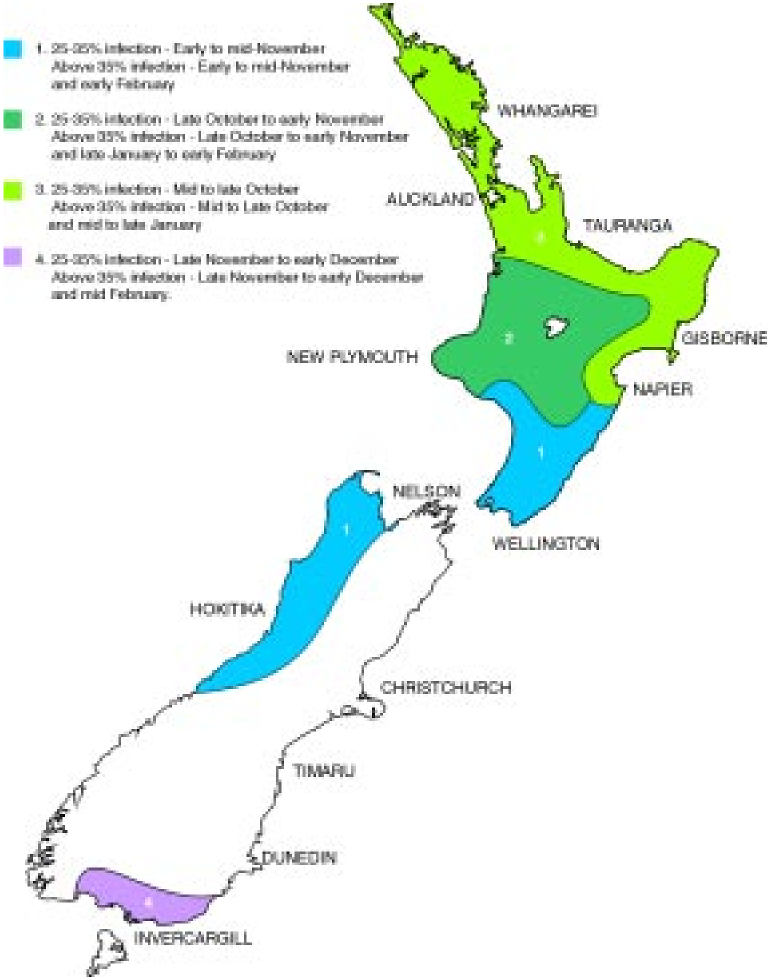


Fig. 6: Recommended times for spraying

3.5 SPRAYABLE LEVEL

The recommended practice is to spray *P. radiata* with a copper fungicide when the overall disease level on the unsuppressed green crown reaches 25%. At infection levels lower than 25%, growth loss can't be measured and it is unlikely that the cost of spraying would be recovered by increased increment. Because disease can build up quickly given suitable climatic conditions (regular rainfall and temperature between 16° and 20°C), spraying stands with low disease levels of 10–15% is unlikely to suppress disease the following season if conditions are optimal for disease development. Stands with high disease levels may require spraying twice in one season (Fig. 6). A double spray is recommended when overall disease levels reach 40% or more. Refer to Chapter 2 for details of disease assessment.

If a stand of *P. radiata* has an infection rating of 25–40% and the stand is due for pruning during that year, it is recommended that spraying is delayed as pruning removes many of the infected branches. In medium-hazard regions pruning could postpone the need to spray for several seasons.

For *P. nigra* and *P. ponderosa,* spraying is often conducted on a maintenance basis to retain stand volumes until the trees are felled. This might entail spraying a percentage of the total area planted in these species in rotation once every 3 years, or spraying at a locally determined overall infection level, usually somewhere between 25% and 50%.

3.6 SPRAY APPLICATION RATE

Five litres of spray are applied per hectare, containing 1.66 kg copper oxychloride (as a 50% wettable powder) mixed with 2 litres of emulsifiable spray oil. Sufficient water is added to give a total volume of 5 litres. For cuprous oxide (as a 75% copper de-dusted wettable powder) the per-hectare rate is 1.14 kg cuprous oxide mixed with 2 litres of spray oil made up to 5 litres with water. The spray mixture is applied using aircraft fitted with Micronair spraying equipment.

3.7 MIXING THE SPRAY

For copper oxychloride:

> Add 180 litres of water to the mixing tank. Then add the contents of one drum of oil (205 litres). Add seven 25-kg bags of copper oxychloride, at a rate which allows the copper to mix without solids building up on the bottom of the tank. Top up to 525 litres with water. This mix will spray 105 ha.

For cuprous oxide:

> Add 180 litres of water to the mixing tank. Then add the contents of one drum of oil (205 litres). Add five 25-kg bags of cuprous oxide, at a rate which allows the copper to mix without solids building up on the bottom of the tank. Top up to 550 litres with water. This mix will spray 110 ha.

Dye is added to the mixture only if copper oxychloride is used, and a quick field assessment of the spray operation is required.

Periodically, check that all the copper has been suspended. This can be done by scraping the bottom of the mixing tank with a shovel or stick. Good agitation should be maintained to keep the fungicide in suspension.

If the copper is packed in polythene bags, inside woven polypropylene sacks, it is strongly advised that the polypropylene sacks be removed and discarded before the bags of copper are placed on the mixing tank. If the sacks are cut on the mixing tank, strands of polypropylene could fall into the tank and block the filters.

Allowing the spray mix to remain in the tank overnight should be avoided if at all possible. Where overnight standing has occurred, great care should be taken to ensure that all the fungicide has been resuspended before use.

The spray mix is about 1.17 times denser than water and so care must be taken not to overload the aircraft. The pilot is responsible for deciding how much spray the aircraft should carry.

3.8 MIXING EQUIPMENT

3.8.1. Checking the Mixing Equipment

Before a mixing tank is used for the first time each day, it should be examined to see that it is clean and that there is no sludge in the bottom. If the tank is made of iron, check the sides for scale as the copper will cause it to fall off during mixing.

See that the sight glass on the tank is functional and calibrated in litres.

All pipework on the tank should be examined to make sure it is in good condition and does not leak. It is important when working off grass airstrips to ensure that areas which will later be grazed are not heavily contaminated with copper by spillage (*see* Section 3.16.1).

A large-capacity filter must be installed in the pipe leading to the aircraft to prevent large particles entering the aircraft spray system. The filter should be cleaned and checked every day.

3.8.2. Agitation

To ensure that the fungicide is properly mixed, the mixing tank should have an efficient agitation system. Mechanical agitation is usually unsatisfactory, and hydraulic agitation should be used. This is achieved by continuous recirculation of the spray mix through a perforated tube running along the bottom of the mixing tank. The perforations are arranged so that jets of spray sweep the bottom of the tank, preventing the fungicide from settling out. It is also recommended that mixing tanks have rounded corners to prevent the accumulation of fungicide deposits.

3.9 AIRCRAFT SPRAY EQUIPMENT

For Dothistroma control the micronair units should be set to produce droplets with a V.M.D. of 65. The settings differ considerably between the different micronair models. Operating manuals for all the different models of micronairs are available as pdf downloads from the Micron website: www.micron.co.uk.

In general, rotary wing aircraft fly more slowly when spraying than fixed wing aircraft. Therefore, for helicopters larger blades on the micronair are used, set at a greater angle to produce a higher rpm in order to produce the desired droplet size.

Care should be taken to brake or disable the rotation of the micronair unit if ferry speeds exceed the recommended spraying speed for a given micronair setting. Exceeding the designed rpm can result in failure and damage to the micronair unit and aircraft.

Aircraft are required to be equipped with flow meters, and the onus of applying the correct rate now rests with the pilot. Most operators use GPS to determine where they have flown and the area they have sprayed, and flow rate problems are quickly identified.

3.10 CALIBRATION OF AIRCRAFT

The aircraft must arrive calibrated to apply 5 litres/ha. Calibration should be checked by the Airstrip Controller prior to commencement of the operation, and must be within ±5% of the required specification.

3.10.1 Checking the Aircraft Spray Equipment

It is important that before any calibration is undertaken, the pilot is asked to spray some water through the Micronairs while the aircraft is on the ground. The Airstrip Controller should check to see that there are no leaks from the pipework and that there is no leakage of spray from the Micronairs after the spray is shut off. The Micronairs should be checked to see that the pitch of the blades is set fully fine, the bearings are not loose, and the cages and blades are in good condition.

3.10.2 Checking the Spray Swath

It is important that before any calibration checks are attempted, the Airstrip Controller is satisfied that the effective spray swath width (width of the spray pattern) is equal to, or greater than, the bout width (distance between two adjacent flight lines).

The following procedure can be used to check the spray swath width; it should not be undertaken if the wind speed exceeds 5 knots.

On flat ground (the airstrip) lay out a continuous strip of paper, or series of paper traps (*see* Section 3.13.2 for details) not more than 1 m apart, at right angles to the direction of the wind. Mark the centre of the trap line with a marker (flag) that can be seen by the pilot.

Partly fill the aircraft spray tank with the usual fungicide mix and ask the pilot to spray at normal spraying height (4–6 m above the trees) and speed over the marker, at right angles to the trap line.

Examine the spray pattern on the paper to determine the effective swath width. The effective swath width is the distance between the points at each end of the pattern where the deposit is half of the maximum deposit. Check also for gross irregularities in the spray pattern, and for large drops which may indicate leaks in the spray system.

3.10.3 Calculation of Spray Output

The spray output from the aircraft is calculated from the application rate, bout width (distance between adjacent flight paths), and the ground speed of the aircraft, by the following formula:

$$\underset{\text{(litres/min)}}{\text{Spray output}} = \frac{\underset{\text{(knots)}}{\text{Speed}} \times 1.852 \times \underset{\text{(m)}}{\text{Bout width}} \times \underset{\text{(litres/ha)}}{\text{Application rate}}}{600}$$

By using this formula the Airstrip Controller can determine the spray output which should show on the flowmeter.

In using this formula it is important to note:

- the output is the sum total for all Micronair units
- the speed is in knots
- the bout width is the distance between two adjacent flight lines and for Dothistroma spraying is usually 20 m unless the aircraft has a smaller effective swath width
- for Dothistroma spraying the application rate is 5 litres/ha.

TABLE 1: Spray output required at different airspeeds to give an application rate of 5 litres/ha when spraying with a 20-m bout width.

Air speed (knots)	Output per minute (litres)
60	18.5
65	20.0
70	21.6
75	23.0
80	24.7
85	26.2
90	27.8
95	29.3
100	30.8
105	32.4
110	34.0
115	35.5
120	37.0

3.10.4 Checking the Spray Output

All aircraft used for Dothistroma spraying are fitted with a flowmeter to measure the spray output. The spray output can be checked by partly filling the hopper with spray mix and asking the pilot to fly at normal spraying speed. After filling the boom with spray and zeroing the flowmeter, the pilot should spray for exactly 1 minute. The output on the flowmeter should be within 5% of that calculated. With a helicopter this procedure can be undertaken while on the ground.

Small adjustments can be made to the spray output by altering the pressure, while larger changes must be made by altering the settings of the variable restrictor units on each Micronair.

Water, rather than the copper spray mix, can be used to check the spray output, but the reading on the flowmeter should then be equal to that calculated × 1.06. This is because the spray mix is thicker than water.

3.11 THE IMPORTANCE OF DROPLET SIZE

The aerial spray operation is aimed at getting a reasonably uniform deposition of fungicide on the pine needles. The spray has to be broken up into many droplets to obtain adequate cover of the many needles in a stand of pine trees. Each time the diameter of a spray droplet is halved, eight times the number of droplets are produced, e.g., the volume of one 800-micron droplet is equivalent to eight 400-micron droplets, or sixty-four 200-micron droplets. Obviously, we should aim to produce the smallest possible droplets that can reach the foliage. The Dothistroma Control Committee asks that aerial contractors aim for the production of a 65-micron droplet. Remember that larger droplets mean fewer droplets and therefore poorer coverage.

The droplet size is too small to reproduce in this booklet, but sample cards are available from your Sector Controller. The correct droplet

“Watch that droplet size!!!”

size should be obtained from the Micronair unit, if it is set up correctly. Large droplets on the traps indicate a malfunction. Usually, this can be attributed to a leak in the system. The other possibilities are incorrect positioning of the Micronair unit, allowing spray to be deposited on the aircraft and then dripping off, or incorrect setting of the blades.

3.12 HOW A MICRONAIR WORKS

When you pull up behind a logging truck at the traffic lights on a wet day, observe the droplets thrown off the tyres as the truck accelerates away. When the wheels are moving slowly you will see large droplets thrown off the tyres. The faster the truck goes, the smaller the droplets become, until when the truck is moving at its normal speed the droplets become so small that they almost form a mist.

The micronair atomiser works in a similar manner. The driving force comes from the air flow rotating the fan blades as the unit is dragged through the air by the aircraft to which it is attached. Spray is fed into the centre of the unit and falls on to the inner perforated tube which is rotating. The droplets thrown off this are caught on the outer gauze cage and then thrown off once more. The faster the cage rotates, the smaller the droplets become. At a given rotational speed, the range of droplet sizes produced is much narrower than that produced by a standard hydraulic nozzle. This means that there are no large wasteful droplets produced.

The speed of rotation is controlled by the speed of the aircraft and the size and pitch of the fan blades. The faster the plane flies, the faster the speed of rotation at any given blade pitch setting, and the finer the pitch at a given flying speed, the faster the rotation.

The spray is fed from the boom to the Micronair via the variable restrictor unit and the diaphragm check valve. Inside the variable restrictor unit is a fixed plate drilled with holes of differing sizes. On this sits a plate with a single hole, which can be rotated by turning the red knob. Gross changes in the flow are made by rotating the knob which aligns the hole with one of the holes in the fixed plate.

The diaphragm is identical to those found on conventional nozzles. When the spray is shut off, the pressure drops and the check valve closes, preventing the spray in the boom dripping out during turns at the end of a spray run, or during ferrying.

3.13 INSTRUCTION FOR CONTROLLERS

Field days are sometimes organised in October, prior to the start of the spray programme, to familiarise Ground and Airstrip/Helipad Controllers with the work. Continuity of staff is an important factor in maintaining standards.

3.13.1 Duties of Airstrip or Helipad Controller during Spraying

These can be summarised as follows:

- To check that the aircraft is correctly calibrated;
- To ensure that mixing and loading are carried out correctly and efficiently;
- To complete records of the operation
  - (a) Record the volume of every spray load and the total volume for each area
  - (b) Record the amount of copper used
  - (c) Note any deviation from the original plan;
- To check that the volume of spray, the quantity of copper used, and the area sprayed all tally at the end of the day;
- To check his records against those of the pilot and rectify any discrepancies. The Controller and the pilot must sign each other's records to certify them correct at the end of each day's spraying.

3.13.2 Duties of Ground Controller

These can be summarised as follows:

- To monitor the wind, temperature, and relative humidity. The Ground Controller must carry an anemometer, thermometer, and hygrometer to enable the meteorological conditions to be monitored. These should be reported to the Airstrip Controller. When making decisions on the suitability of conditions for spraying, the Ground Controller needs to remember that it may take at least 30 minutes to spray another load, by which time the weather may have deteriorated.
- To stop the spraying when conditions become unsuitable for spraying.

It is important that the Ground Controller has good radio communications with the Airstrip Controller.

3.14 CLIMATIC RESTRICTIONS ON SPRAYING

High temperatures, low humidity, and wind can reduce the amount of spray landing on the foliage. Experience has shown that often more spray is deposited as the wind strength increases. Therefore, the limiting factor is more likely to be the turbulent conditions which occur with increased wind strength, making it unsafe for the pilot to fly at the spray height of between 4 and 6 m above the trees.

The pilot will indicate when flying conditions become too dangerous. Traps should be carefully examined as the temperature approaches 20°C. High temperatures on still days will cause the spray droplets to rise on thermals, rather than land on the trees or traps.

Care should be taken in assessing the spray deposition if the relative humidity drops below 45%.

3.15 RESPRAYING AFTER RAIN

Research has shown that copper is progressively lost by a weathering process even in the absence of rain. In average climatic conditions, copper persists on the needles for 2 to 3 months. Rain does increase the loss of copper to some extent but, provided the fungicide spray has dried before the rain starts, there is no need to respray. Whether a spray has dried or not is sometimes difficult to define. Spray falling on dry foliage would dry in a matter of minutes, but if the foliage is wet with dew then the spray will dry only as the dew evaporates.

3.16 ENVIRONMENTAL CONSIDERATIONS

3.16.1 Dothistroma Spraying and Grazing Stock

Copper is an essential element for all living things, but in excessive amounts it is poisonous (Acute oral LD50 for male rats for copper oxychloride = 1470 mg/kg and for cuprous oxide = 470 mg/kg). In New Zealand, cattle which broke into a storage shed and consumed copper fungicides died. In South Africa, sheep have died after grazing in an orchard that had been sprayed repeatedly with copper fungicides for many years. Dothistroma spraying is equivalent to top dressing with

0.83 kg copper metal equivalent per hectare, and there is no reason why cattle cannot be grazed under sprayed trees. With sheep the same applies, provided they have been neither stressed in any way, nor exposed to ragwort. The toxins in ragwort affect the liver so that it is unable to deal with excessive amounts of copper.

It is recommended that stock be kept off airstrips for 3 weeks after they have been used by planes spraying copper fungicides. If large areas have been sprayed from a particular airstrip it would be advisable to fence off the storage and mixing area for 2 months. If major spillages have occurred, the top 5 cm of contaminated soil should be removed and buried.

3.16.2 Spray Drift

To treat the edges of stands in windy conditions, pilots will have to fly outside the edge of the stand and drift the spray into the trees. As with all aerial spraying, care must be taken to ensure that the spray does not drift into adjacent sensitive areas such as kiwifruit and other orchards. These stands should be sprayed when a positive wind, in excess of 5 km/h, is blowing away from the sensitive area. Care should also be taken to avoid contamination of roofs of buildings.

3.17 REASONS FOR FAILURE

If the next July/August assessment after spraying indicates no (or only a very small) reduction in infection level, it is possible that the treatment has not worked as well as it should have. However, if the climate during the November to March period was favourable for the disease it is likely that infection levels would have been significantly higher if spraying wasn't undertaken. Without the presence of unsprayed control blocks it is not possible to determine the success of spraying definitively. Factors that lessen of efficacy of spraying are:

- Incorrect formulation of the copper fungicide. This is a most unlikely fault (*see* Section 3.2)
- Faulty mixing of the fungicide before it is put into the aircraft (Section 3.7)
- Faulty application — there may not have been correct coverage (Section 3.11)

- Rain before copper spray dried on foliage (Section 3.15)
- Spraying conducted outside the climatic tolerances (Section 3.14)
- Spray applied at wrong time of the year (*see* the recommended treatment times Fig. 6)
- Infection level too high for only a single spray to reduce the level significantly
- Unseasonable climatic conditions, particularly at the time of spraying, enhancing disease development
- Topographical features such as gullies sprayed from too great a height, or ridge tops subjected to excessive winds
- The wrong stand sprayed because of a pilot navigation error, or because of incorrect instructions (faulty maps), and, of course, a lack of ground control. This type of fault is unlikely to occur with the use of a GPS.

Although spray traps are now very rarely used, an example of a form that accompanied spray traps is shown in Appendix I. This could be used as a template for ground controllers to record conditions prevailing at the time spraying was carried out. In the event of failure this information could be retrieved to determine if climatic conditions contributed to the lack of success.

4. CONTROL OF INFECTION IN NURSERY SEEDLINGS

The present spraying programme is merely a means of minimising infection, not eradicating it (Jancarik 1969), and should keep the disease to a low level. The lower the disease level on the planting stock, the longer it will be before the plantation reaches infection levels which will necessitate spraying. It is poor nursery practice to produce planting stock with noticeable *Dothistroma* infection. Two aspects are important for the production of low-infection rated seedlings: hygiene and chemical control.

4.1 HYGIENE

4.1.1 Old Stock

Whenever possible all old stock should be removed from the nursery to prevent a build up of infection. In nurseries where 2/0 stock is produced, spraying should be continued in their second year. Close stocking in nursery seedbeds encourages the disease and leads to high infection levels that serve as an inoculum source for nearby young crop seedlings.

4.2 CHEMICAL CONTROL

4.2.1 1/0 stock

It is recommended that a monthly or 6-weekly application of 2.6 kg cuprous oxide/ha (75% wettable powder) be made. Spraying should be started in October or when the seedlings are about 2.5 cm high and continued until the end of March. The application volume is not critical and can be in the range 100–500 litres/ha.

4.2.2 2/0 and Older Stock

Spraying should recommence in October and continue until the end of March at the above rates.

4.3 PHYTOTOXICITY

The use of copper fungicides in colder climates may produce a phytotoxic effect in the form of burning of the foliage and, in severe cases, stunting of the seedlings. “Phytotoxicity appears when the temperatures fall below freezing point. At first small pale discolourations and dish-like indentations appear on the radiata pine needles after the first frost. Gradually they expand and broaden with increasing cold, turning red-brown, and cover the needle” (Jancarik 1969). Minor changes which may occur will not affect the growth or value of seedlings.

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APPENDIX 1

SPRAY TRAP ENVELOPE COVER WITH QUESTIONNAIRE

DOTHISTROMA PINI GROUND CONTROL

……………………………………………..FOREST

Stand ……………………………………………… Species ………………………………………………

Ground Controller ……………………………… Date ………………………………………………

Aerial Company ………………………………… Pilot ………………………………………………

Time Started ……………………………………… Time Stopped ………………………………………

Conditions at start — Temp ……… Humidity ……… Wind ……… Direction ………

Temp ……… Humidity ……… Wind ……… Reason ……… — Conditions at finish

Direction of Flight Lines ……………………… Rainfall 24 hours ……………………………

Number of traps laid out ………………………

Area sprayed ……………………………………… Was respraying required ……………………

N.B. Attach map with trap positions marked approx.

APPENDIX 2

CALENDAR OF EVENTS

Mid June	Dothistroma Control Committee meets to discuss spray recommendations, and to review the amount of copper fungicide held in store.
July to early August	Assessment of *Dothistroma* infection levels on *P. radiata.* Survey generally conducted by contracted Forest Health personnel.
Second week of August	Secretary of the Dothistroma Control Committee to receive all North Island maps and schedule of areas to be sprayed. South Island requirements are handled by a Controller in the South Island.
Second week of September	Tenders are called for the aerial application of the copper fungicide.
Fourth week of September	Flying tenders close.
Early October	Dothistroma Control Committee considers flying tenders and reviews expected copper fungicide stocks which will be available after the current spray programme.
October	Instruction day for Ground and Airstrip Controllers. These are not always held.
October to December and sometimes January	Aerial spraying for the control of *Dothistroma* on *P. radiata, P. nigra* subsp*. laricio,* and *P. ponderosa* is conducted. *See* Section 3.3.

November	Dothistroma Control Committee organises copper fungicide tenders for the following year and reviews progress of the current spray programme.
November	Time for the assessment of *Dothistroma* infection levels on North Island *P. nigra* subsp*. laricio* and *P. ponderosa.*
January	Time for the assessment of *Dothistroma* infection levels on *P. nigra* subsp*. laricio* and *P. ponderosa* in the South Island.
February to March	Dothistroma Control Committee meets to review the completed spray programme and progress towards purchasing copper fungicide.
April-May	Dothistroma Control Committee meets to decide the successful tender for the copper fungicide.

APPENDIX 3

ANNUAL SPRAY PROGRAMMES CONDUCTED TO DATE FOR THE NORTH ISLAND

Programme year	Sprayed area (ha)	Programme year	Sprayed area (ha)
1966/67	32,513	1985/86	102,712
1967/68	21,785	1986/87	150,942
1968/69	10,727	1987/88	85,618
1969/70	11,581	1988/89	88,441
1970/71	9,693	1989/90	119,121
1971/72	31,195	1990/91	97,590
1972/73	28,929	1991/92	78,234
1973/74	14,361	1992/93	63,280
1974/75	24,865	1993/94	49,102
1975/76	61,589	1994/95	74,450
1976/77	62,172	1995/96	115,385
1977/78	24,268	1996/97	99,605
1978/79	2,157	1997/98	43,681
1979/80	60,798	1998/99	73,328
1980/81	96,452	1999/00	37,813
1981/82	101,533	2000/01	55,273
1982/83	86,822	2001/02	97,106
1983/84	37,197	2002/03	182,765
1984/85	127,799	2003/04	72,352