CONTROL OF DOTHISTROMA NEEDLE BLIGHT IN THE *PINUS RADIATA* STANDS OF KINLEITH FOREST

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ABSTRACT

Since 1966 copper fungicides have been aerially applied to control Dothistroma needle blight within the *Pinus radiata* D. Don stands of Kinleith Forest. The total cost of this programme has been $18,400,000 (1988 dollars). Current control costs are substantially less than they were when spraying began because of improvements in application techniques and reduction in spray volume. Spray records for 40 stands (10 300 ha total) showed that the average spray frequency per hectare per rotation was 5.45 (range 2.10–10.30). Yield information was available for 10 of the 40 stands. There was no correlation between expected yield and spraying frequency for these areas. A theoretical Dothistroma-resistant breed of *P. radiata* was evaluated in terms of spraying cost. Savings of 56% are estimated if this breed was established within Kinleith Forest in place of existing breeds.

Keywords: aerial spraying; genetics; yield; *Dothistroma pini; Pinus radiata.*

INTRODUCTION

Dothistroma pini Hulbary, a fungus which causes needle blight in *Pinus* spp., was first noticed in New Zealand in 1962 (Gilmour 1967). It was thought that the fungus was introduced into New Zealand from East Africa where it had been identified in 1957, eventually causing the abandonment of the *Pinus radiata* plantations of that region (Gibson 1979). No other disease, since or before, has had as large an effect on the New Zealand exotic estate in terms of potential yield impact, research effort, and control costs.

East African work showed that the disease could be controlled by copper-based fungicides (Gibson *et al.* 1964) and subsequent New Zealand work (Gilmour *et al.* 1973; Olsen 1971) indicated that the control of Dothistroma by the aerial application of copper oxychloride was operationally feasible.

Dothistroma was first discovered within Kinleith Forest in 1962 and NZFP Forests Limited has aerially sprayed infected stands since 1966. The spraying strategy closely follows the recommendations of Kershaw *et al.* (1988). Stands in the age-classes susceptible to the needle blight (<16 yr) are surveyed from the air in mid-winter and the average percentage of crown infection in each stand is assessed by experienced observers. Stands are classified as: less than 15% of the crown infected — no spray needed; 15%–30% crown infection — one spray application in early summer; >30% crown infection — two spray applications, early summer and late summer. The fungicidal suspension is applied at a rate of 5 *l*/ha (1.66 kg copper oxychloride and 2 *l* emulsifiable spray oil with sufficient water to make up the volume to 5*l*). The fungicide is applied from fixed-wing aircraft through Micronair Atomizers (Micronair, UK). NZFP Forests Limited has been using this spraying prescription since 1983; before then, higher quantities of fungicide and higher application volumes, using boom and nozzles, were standard.

MATERIALS AND METHODS

Kinleith Forest is the largest privately owned forest in New Zealand (Fig. 1). Most of its 145 000 ha have been established with *P. radiata* (current average age 16.3 years).

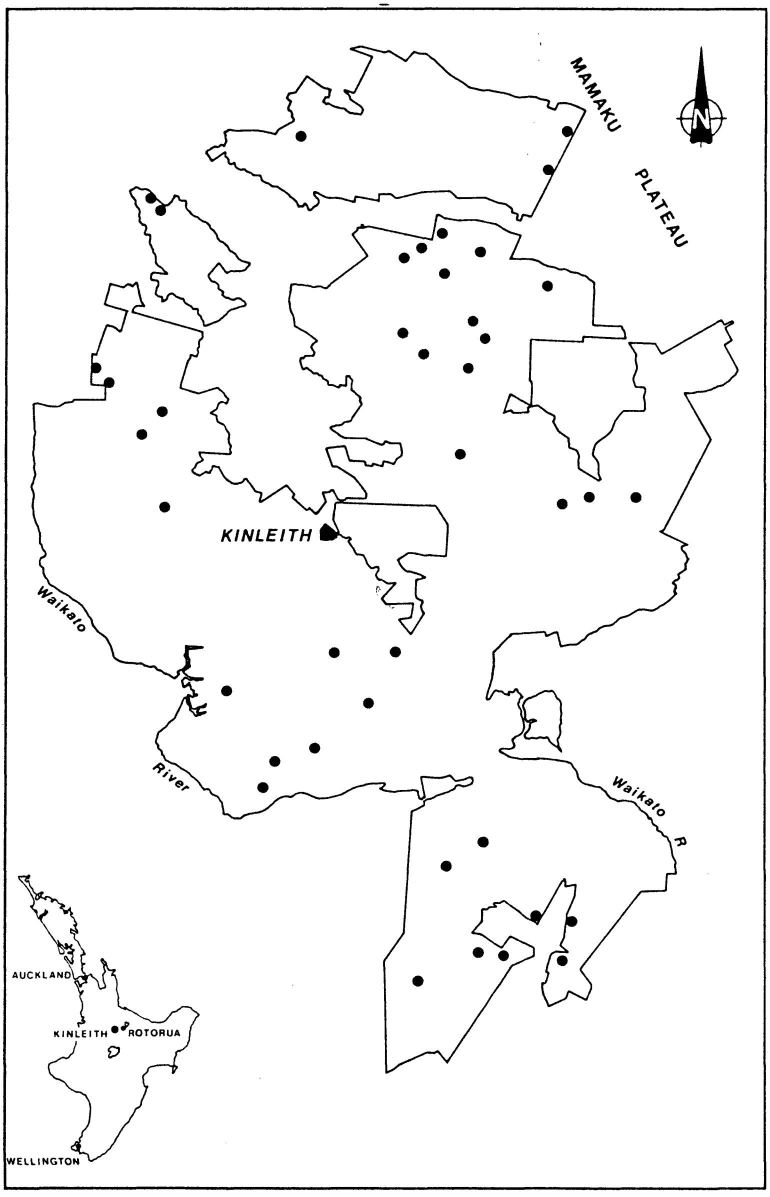

FIG. 1 — Location of Kinleith Forest and the sites used for spray frequency analysis.

Rainfall throughout the forest is generally moderate (1548 mm/yr, Kinleith Met. Station) although heavier rainfall occurs in the Mamaku Range (2128 mm/yr, Mamaku Met. Station). The Waikato River is a significant component of the forest's local geography with the river valley subjected to long periods of mist.

Four aspects of the spray programme were examined. These were:

- Cost of spraying;
- Frequency of spraying;
- Potential value of using stock with inherited disease resistance;
- Effect of Dothistroma needle blight on yield of sprayed stands.

Cost of Spraying

Existing company records were used to provide costs of spraying per hectare for 1966 to 1988. It was assumed that the total cost of spraying could be calculated by adding the cost of copper and oil, aircraft operation, ground control (monitoring of spray deposition), supervision (spraying co-ordination, maintenance of records, drafting of maps, and airstrip control), and survey. Records were not complete so the mean component cost, for either the period 1966–82 or the period 1983–88, was substituted for any year that did not have a cost for that component. The two periods had to be separated because of a major change in spraying regimes in 1983. Costs were converted to 1988 dollars using the Consumer Price Index.

Frequency of Spraying

Forty sample stands (average size 257 ha, range 55 to 980 ha) in the susceptible age-class (<16 yr), scattered over Kinleith Forest, were chosen (Fig. 1). Using maps which recorded the boundaries of the sprayed areas for every year from 1970 to 1988, the boundaries of the sprayed areas and the boundaries of the sample stands were visually compared and the proportion of the area of the sample stands sprayed was determined. A double application was deemed equivalent to two single sprays and the number of times parts of the 40 sample stands were sprayed over the period that they were included within annual surveys was calculated. It was assumed that this score is an indication of the severity of Dothistroma infection. For example, in 1977 sample stand x received a single fungicide application over 70% of its total area. In 1979 40% of the stand had two applications with another 30% receiving a single application. In 1983 the whole stand received another single application. No further spraying was required before the stand was excluded from the survey programme at age 16. The Dothistroma infection score for this stand is calculated as: $0.7 + 0.8 + 0.3 + 1.0 = 2.8$.

Potential Value of Inherited Disease Resistance

Costs presented in this paper were used to estimate the potential dollar savings in spraying costs if a breed of *P. radiata* resistant to Dothistroma needle blight had been established in Kinleith Forest. Such a breed has been proposed (Carson 1989) although it is not yet commercially available. Savings were calculated for the period 1983–88 only, because application techniques and fungicide quantities and volumes were markedly different before this time, with reliance on the following assumptions:

(1) Spray costs were calculated as above.

(2) The proposed new breed gives a reduction of 15% in infection severity.

(3) The maximum infection level for a double sprayed area was 80%.

(4) The broad categories used to rate infected stands do not allow easy interpretation of the effects of a 15% reduction in infection level. To overcome this, disease levels were estimated assuming that the actual levels of infection were evenly distributed within a spray class. A block that had a single spray could have had a real infection of 17% or 27%, with equal likelihood.

The results have been calculated by subtracting 15 from the estimated infection levels and moving a block into a lower class where applicable. For instance, areas that had a real infection level of 28% would have an infection level of 13% if the forest had been established with the resistant breed. The cost of spraying those hectares is saved. The same logic has been applied to the double spray category; a non-resistant score of 40% would become 25% and the cost of one spray is saved. Infection levels greater than 45% would remain within the double spray category irrespective of breed.

Effect of Dothistroma Needle Blight on Yield of Sprayed Stands

It has been suggested that yield may be reduced in areas of heavy infection despite remedial spraying (Woollons & Hayward 1984). If that happens, areas of heavy infection would be negatively correlated with yield.

Growth data collected for NZFP Forests Ltd inventory purposes were available for 10 of the 40 sample stands chosen for the spray history analysis. Diameter distributions from assessments made at age 10 were used in the Kinleith Forest Growth Model (Woollons & Hayward 1985) to predict yields at age 30. The predicted yield was compared with aerial spraying frequency to identify the yield implications of Dothistroma infection in the presence of remedial spraying.

RESULTS

Cost of Spraying

Over the period 1966–88, $18,400,000 (in 1988 dollars) was spent on aerial spraying. Costs per hectare have declined since spraying began, partly due to reduced spray volumes leading to reduction in flying time, partly due to reduced fungicide doses leading to reductions in chemical cost. The average cost of $44.72/ha in 1966 was substantially higher than the current costs of spraying (Table 1).

Frequency of Spraying

The average spray frequency for the 40 sample stands was 5.45 (s.e. = 0.31). The area with the lowest disease hazard was sprayed 2.10 times and the area with the highest disease hazard was sprayed 10.30 times. When the sample stands are grouped according to sub-divisions of the forest a clear pattern of disease prevalence occurs (Fig. 2). The heavier infection severities associated with the Waikato River valley (Maraetai and Commons areas, Fig. 2) and the Mamaku Range (Mamaku and Pukerimu areas, Fig. 2) fit with the observations of field staff at Kinleith. Sample stands in each of these areas have required spraying, on average, more than 6 times during the period of disease susceptibility.

TABLE 1–Cost of spraying Kinleith Forest

Year	Area sprayed (ha)	Cost (1988 NZ$) of Flying /ha	Supervision /ha	Copper + oil/ha	Ground control /ha*	Survey total†	Total cost ($)	Cost ($/ha)
1966	8 195.7	14.39	5.02	20.95	3.37	8,092.7	366,491	44.72
1967	12 172.6	16.57	5.02	32.58	3.37	8,720.7	697,126	57.27
1968	5 238.6	16.86	5.02	37.67	3.37	9,300.1	338,913	64.70
1969	6 487.9	19.27	5.02	37.43	3.37	10,290.5	432,588	66.68
1970	6 204.7	18.75	4.36	41.77	3.37	11,683.0	435,154	70.13
1971	16 162.0	19.16	5.02	31.57	3.37	17,255.7	972,753	60.19
1972	8 813.6	18.56	4.71	26.82	3.00	17,376.7	485,291	55.06
1973	10 432.8	17.82	4.54	21.71	3.37	20,940.9	515,873	49.45
1974	3 580.0	20.95	4.54	24.38	3.38	16,359.2	206,983	57.82
1975	20 167.0	21.93	6.12	22.56	2.79	18,799.6	1,095,717	54.33
1976	25 192.0	14.37	6.14	20.93	2.80	16,359.2	1,130,853	44.89
1977	8 650.1	16.36	4.82	16.76	3.98	23,922.2	386,534	44.69
1978	580.0	15.78	4.64	15.32	4.54	23,751.5	47,114	81.23
1979	39 946.5	15.19	4.34	15.19	3.11	54,642.5	1,565.819	39.20
1980	58 123.0	11.49	5.02	16.88	3.37	40,011.9	2,176,613	37.45
1981	48 181.0	9.33	5.02	14.58	3.37	40,409.5	1,596,656	33.14
1982	38 017.5	12.17	5.02	14.01	3.37	40,493.8	1,354,759	35.64
1983	19 137.5	11.55	1.17	7.52	1.38	40,294.0	454,047	23.73
1984	58 833.5	8.39	1.17	9.10	1.38	40,333.7	1,219,357	20.73
1985	32 426.0	7.21	1.17	9.03	1.38	63,239.6	672,524	20.74
1986	58 385.0	6.02	2.00	10.01	1.58	64,050.2	1,208,980	20.71
1987	39 624.0	4.17	1.17	6.59	1.38	35,988.8	563,384	14.22
1988	30 589.0	4.51	1.17	8.00	1.17	22,600.0	476,847	15.59
							18,400,376	

* Ground control of spray operations

† Survey costs are represented as total costs rather than per-hectare-sprayed costs as they are directly linked to the amount of susceptible forest rather than the area sprayed. To report survey information on a per-hectare-sprayed basis would be confusing.

Potential Value of Disease Resistance

The area sprayed in 1983–88 and the area likely to be sprayed if the forest had been established with the resistant breed are presented in Table 2. The associated costs are presented in Table 3. When the 15% reduction in infection severity is applied to the area sprayed, there are large reductions in areas requiring spraying. Combining the cost information with the reduced hectares achievable with the resistant breed, costs would have been reduced by 56% ($467,000/year).

Effect of Dothistroma Needle Blight on Yield

The yield at age 10, predicted yield at age 30, the age-10 stocking, and the spraying frequency of 10 stands are shown in Table 4. Correlation between spray frequency and age-30 yield was poor ($r = +0.511$, $p = 0.131$). Growth predictions showed that the stand that was sprayed most often was also expected to yield the highest volume although no clear pattern emerged from the data.

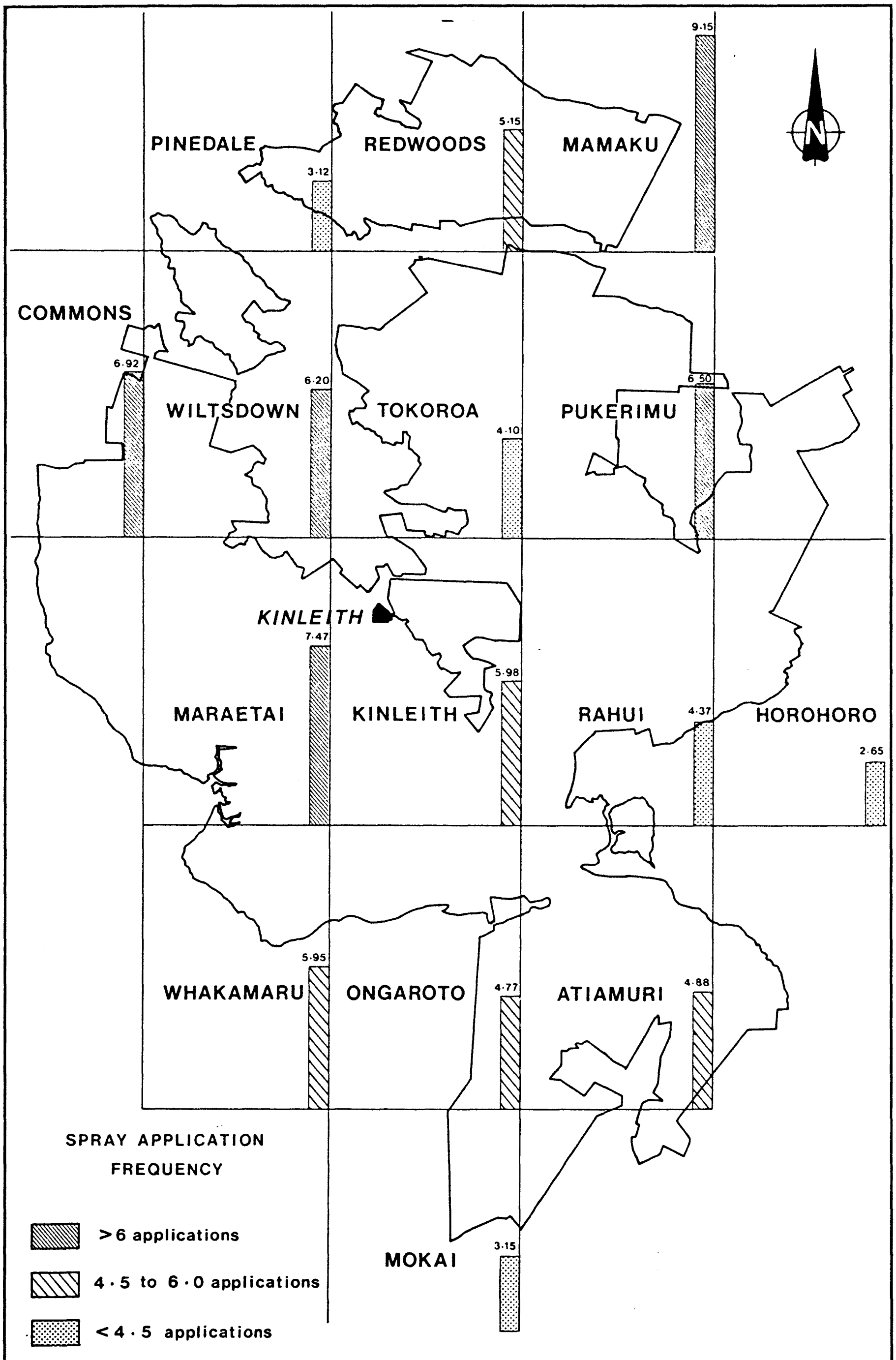

FIG. 2 — Average historic spray frequency of 15 subset forests of Kinleith Forest.

TABLE 2–Actual area sprayed and estimated area needing spraying assuming a 15% reduction in infection severity

Year	Actual area (ha)			Estimated area (ha)		
	Single spray	Double spray	Total	Single spray	Double spray	Total
1983	1 074	9 032	19 138	2 777	6 322	15 422
1984	45 328	6 753	58 834	4 859	4 727	14 313
1985	26 126	3 150	32 426	2 578	2 205	6 988
1986	29 255	14 565	58 385	6 198	10 196	26 589
1987	32 448	3 588	39 624	3 105	2 512	8 128
1988	20 687	4 982	30 589	2 788	3 487	9 762

TABLE 3–Estimated cost savings (1988 NZ$) by the use of stock resistant to Dothistroma needle blight

Year	Actual cost	Estimated cost	Savings
1983	454,047	373,707	80,340
1984	1,219,357	327,168	892,189
1985	672,524	194,542	477,982
1986	1,208,980	585,459	623,522
1987	563,384	144,175	419,209
1988	476,847	167,566	309,281
	4,595,139	1,792,617	2,802,522

TABLE 4–Spray application frequency and expected yield in 10 stands (1970–88)

Block	Date established	No. of applications	Volume at age 10 (m^3/ha)	Stocking at age 10 (stems/ha)	Predicted volume at age 30 (m^3/ha)
Pukerimu	1970	5.75	90.25	664	741.8
Kinleith	1971	6.45	84.45	913	705.3
Rahui	1972	4.80	110.15	1182	698.2
Horohoro	1971	2.65	181.51	1394	736.5
Whakamaru	1970	7.55	203.49	1142	806.4
Whakamaru	1971	4.35	194.91	1634	714.7
Ongaroto	1970	3.00	182.67	1513	709.3
Atiamuri	1972	5.75	187.89	1270	772.2
Atiamuri	1970	5.40	122.93	1453	696.1
Atiamuri	1972	2.95	113.11	1045	709.1

DISCUSSION

The per-hectare cost of operational spraying is not high compared with other silvicultural aerial operations. The cost of aerial application of fertiliser (urea in *Eucalyptus* stands) is nine times the cost of Dothistroma spraying, aerial application of weedicides (Velpar for releasing) costs 22 times, and pre-plant desiccation spraying costs 10 times (NZFP internal costing data; all operations use helicopter). However, the total number of hectares with levels of Dothistroma infection high enough to threaten to reduce yield and necessitate spraying is so large that spraying Dothistroma needle blight is the most costly aerial operation undertaken in Kinleith every year.

The average spray frequency per stand is higher than initial research into operational spraying indicated. Gilmour *et al.* (1973) suggested that only one or two spray applications may be neccessary in a rotation. Gibson (1972) indicated that adequate control may be obtained by three or four applications. The higher frequencies recorded at Kinleith are not entirely unexpected as Kinleith Forest lies in a region with wet summers, deep gully systems, and extensive mist, all of which favour development of the needle blight.

Reduced costs of fungicide application per hectare are a good example of the value applied research offers the forestry industry. The current application volume (5 *l*/ha) is perceived to be at the lowest for effective application of copper oxychloride fungicide (J. Ray, pers. comm.). The question of reducing Dothistroma control costs thus becomes a matter of directly reducing disease levels rather than refining aerial application techniques. Breeding for disease resistance is a positive step in this direction and the potential cost reduction calculation in this paper is encouraging.

The opportunity cost associated with establishing a breed with intrinsically less growth and form potential than alternatives would be of concern to forest managers. The 6% difference in volume indicated by Carson (1989), between the best general breed and her proposed resistant breed, is significant in management terms. However, this theoretical difference is unlikely to hold true, as the growth and form gain trials have been established across a broad range of New Zealand sites rather than on sites that suffer from repeated Dothistroma infection. It is probable that a growth and form breed will not perform to predicted potential on these sites, while the Carson breed has been developed on such infected sites. This supposition will require clarification before managers can accurately determine the best breed option for sites within their forests.

Yield loss attributable to Dothistroma infection in the presence and absence of fungicidal spraying has been quantified on an area basis by two trials in the past (van der Pas *et al.* 1984; Woollons & Hayward 1984). The findings of the authors did not entirely agree; van der Pas *et al.*, from a number of sites, concluded that yield losses were not great when spraying at an operational level is maintained. Woollons & Hayward, on a heavily infected Kinleith Site, showed that yield was being affected despite spraying when crown infection reached 25%. Resolving this difference may be possible by comparing a sufficiently large number of forest stands with known yield data and known disease history. Significant correlations could be expected if heavy infection levels lead to yield loss, despite spraying. The small sample provided within this paper indicates no relationship between yield and disease history. While this finding supports the view that the current and past control programmes are providing adequate protection, the small sample size involved, the complexity of disease and spray frequency interaction, and the absence of any pattern at all caution against such an interpretation.

CONCLUSIONS

Despite the low cost per hectare, the annual bill for aerial spraying is high within Kinleith Forest. The indications are that this budget could be reduced not by refinement of well-refined spraying techniques but by utilising known rankings of Dothistroma resistance to produce a *P. radiata* breed that requires less spraying. It has yet to be empirically determined whether a breed such as this will produce additional gains or losses in yield terms. The optimal planting strategy for Kinleith Forest in the future will be to use historical disease information, as presented here, to target sites for a general-purpose breed or the Dothistroma-resistant breed. Where past history indicates frequent spraying, then the resistant breed should be established; on healthier sites standard breeds should be established.

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