KEYNOTE ADDRESS MAINTAINING HEALTH IN PLANTATION FORESTS

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ABSTRACT

In reviewing the current mechanisms for maintaining health in plantation forests, this paper suggests that the health of New Zealand's radiata pine (*Pinus radiata* D. Don) forests has declined over the last 30 years and can be expected to continue to decline. There is a need to monitor forest health, largely for the predictive capability this will provide. It is also necessary to have alternative replacement species for the time when radiata pine may become uneconomic.

It is proposed that in the next decade the attitude to forest health in the industry should be somewhat modified from its present "specialist" status, and instead forest health should be regarded as a normal economic component of silvicultural decision-making. Forest staff should be more involved in health maintenance and forest health data should be incorporated in decision-making models.

Keywords: plantation forest health; pests; diseases; *Pinus radiata*.

INTRODUCTION

The key word in the title of this paper would appear to be "health", and faced with having to talk about it for 50 minutes, I did the traditional thing of looking it up in the dictionary to ensure that I knew what I was talking about. The word comes from a Germanic word meaning whole, but beyond that the dictionary was not helpful. It related health only to people, an interesting point in itself.

There are clearly a number of reasons for which forests may not be whole or healthy. These include damage from insects and diseases, animal pests, plant parasites, and aerial pollution. But they also include physiological disorders, which may result from such factors as water tables that are too high or too low, or from nutrient deficiencies or imbalances. Because the papers at this meeting are largely oriented toward insects and diseases, I too will concentrate in that area. Much of my thrust, however, will be to talk about forest health in economic terms, and I would point out that all of the above factors affect the economics of growing a forest crop. All are likely to reduce increment, and all can be manipulated to the benefit of the crop - at a cost.

I propose to talk primarily about New Zealand - not in defiance of the name of the workshop, but because I have more hard data about New Zealand than elsewhere in the South Pacific. However, my talk relates essentially to principles and philosophies, and these I hope are generally applicable to the South Pacific as a region.

HISTORY OF FOREST HEALTH

New Zealand has planted forest trees from other countries since the mid 1800s – initially only locally in treeless areas, but more seriously and on a wider range of sites since the 1930s. The area of exotic plantation forest has increased from 337 000 ha in 1950 to 1.2 million ha today. Prior to the late 1920s, forest health was not seen as an issue of great significance, but in 1929 a Forest Biological Research Committee was set up. The Forest Service then appointed both a pathologist and an entomologist in 1930 (de Gryse 1955). During the early 1930s these workers produced a number of publications, but interest was not maintained and the positions lapsed later in the decade, when a *laissez faire* attitude to forest health developed.

No change occurred to that situation until the mid-1940s when *Sirex noctilio* Fabricius began to cause substantial mortality in the (by then) overstocked forests of the 1930s plantings (Rawlings 1948; Rawlings & Wilson 1949). Research quickly showed a major implication of silvicultural management in the problem. As a result of that outbreak, and a subsequent flare-up of populations of *Pseudocoremia suavis* Butler in 1951–52, the then Director of the Forest Service (A.R. Entrican) invited the Canadian forest entomologist J. J. de Gryse to recommend on "the essential measures and practices to adopt to safeguard the country's exotic forests from the threat of insect and pathological epidemics". De Gryse's broad proposals involved the classical techniques of education, survey, and control, backed up by research. His report was positively received and all his recommendations were promptly adopted: the organisations set up have been maintained to the present. A quarantine system to protect New Zealand's primary production was of course already well in place before that time.

SUCCESS OF THE FOREST HEALTH PROGRAMME?

With all of the four key ingredients of quarantine, monitoring, research, and management awareness thus in place by the mid-1950s, it is pertinent to review how successful New Zealand has been in maintaining the health of its plantation forests since then. As a university teacher I find myself considering a grade somewhere between C and D, i.e., maybe about 50%. On the plus side, we are still growing radiata pine in what we believe is a commercially effective manner. On the debit side, however, our economic capability to grow Douglas fir *(Pseudotsuga menziesii* (Mirbel) Franco) and ponderosa *(Pinus ponderosa* P. et C. Lawson) and Corsican pines *(P. nigra* ssp. *laricio* (Poiret) Maire) economically on many sites has been greatly reduced since the 1950s by *Phaeocryptopus gaeumannii* (Rohde) Petrak and *Dothistroma pini* Hulbary respectively. (We had, of course, as early as the 1930s run into insect problems with eucalypts of the blue-gum group and some other species.) Despite a substantial expenditure on quarantine, health monitoring, and R & D, and despite some opportunity costs with respect to management options, I suggest that we rate little better than a passing grade.

As you know, we now (in New Zealand) maintain what is essentially a radiata pine monoculture. How has its health fared since the 1950s? That is a significant question to ask because it leads to the realisation that there is no quantitative answer. There is no formal monitoring system in place which will tell a politician, a forest owner, or an academic writing a keynote address whether our radiata pine plantations are as healthy now as they were in the 1920s or the 1950s. There are certainly some indications, but I wonder if that is good enough for an industry whose forests are worth between $2 billion and $12 billion, and for which the necessary downstream processing plants will have a value of around $10 billion (National Business Review 14.2.89).

If we don't have facts, what do the indications tell us? What they suggest to me is that, during the last 35 years, the health of radiata pine in New Zealand forests has deteriorated considerably. But if I am right, we as a sector have not admitted that to ourselves. I suspect this may be the first time that anyone in New Zealand has publicly expressed that belief. Health changes are gradual and easily overlooked. We are in the habit of regarding our forest as healthy. We have no monitoring system in place to tell us otherwise.

What is the evidence for my contention? Firstly, of course, personal impression. I believe that I am seeing considerably more ill-health now than I did in the late 1950s and early 1960s. However, a semi-formal confirmation that needle retention has declined over that time comes from Dr R. Woollons (pers. comm.) who carried out many sectional measurements of trees in NZFP forests over that period. It is his contention that, up until the late 1960s, it was extremely difficult to see and measure upper stem diameters because of foliage density. Since that time, foliage retention has been sufficiently low that sectional measurement on standing trees has posed no difficulties.

Secondly, forest health professionals who recently visited the natural stands of radiata pine in California, have commented positively on the appearance of stands there relative to New Zealand. G. P. Hosking & J. Bain (unpubl. data) stated "in general, as far as tree health is concerned, the appearance of *P. radiata* in California is noticeably better than in New Zealand. Foliage colour and retention are better and mortality is lower." Earlier visitors (Silviculturist H. V. Hinds, geneticists I. J. Thulin and W. J. Libby, in the 1950s and myself in 1973) were not struck by that fact. Were we unobservant, or has forest health deteriorated since then?

Thirdly, a recent 4-week visit I made to some of the forests of Europe confirmed my thinking. I found it both fascinating and disturbing that the worst examples I could find of the much vaunted forest decline in four European countries were trivial relative to examples of ill health I saw almost daily as the Branch Head of Forest Pathology & Entomology at FRI between 1978 and 1985 - and that despite European levels of pollution that I believe to be at least an order of magnitude greater that those found in New Zealand, and despite a host of physiological evidence at the conference I attended, that these levels of pollution were severely affecting almost every physiological parameter of a tree that could be measured. If trees can look so healthy despite those levels of physiological impairment, then it suggests to me that many of our forests may have some real problems!

As well, however, I think there are also some quantitative indications (although I concede they are no more than indications) that the health of our plantations is deteriorating. If one persists with the criteria of health as being absence of mortality, good foliage colour, and long foliage retention, then several pathogens significantly reduce health. *Cyclaneusma* spp. have been recorded in New Zealand since the 1950s. In the 1960s and even early 1970s there were still those who argued that *Cyclaneusma* was a saprophytic rather than a parasitic genus. That is no longer arguable in the 1980s (thanks to the research of Gadgil 1984). The large areas of infection reported in the surveys initiated by van der Pas (van der Pas, Bulman & Horgan 1984; van der Pas, Bulman & Slater-Hayes 1984; van der Pas, Slater-Hayes, Gadgil & Bulman 1984; Bulman 1988) in my recall proportionately exceed by an order of magnitude anything reported to the end of the 1950s. This may simply reflect current weather patterns (Gadgil (1984) has shown that severe needle cast is associated with mild wet winters), but I wonder if it could also reflect trees which have less capacity to resist infection than in the past? The relationship between the pathogen and the only sometimes-associated needle cast has always been difficult to explain. Is it unrealistic to involve the "physiological health" of the tree as one component?

Dothistroma pini, because it is sprayed annually, provides a better documented quantification of changes with time than other pathogens. Data are presented in Fig. 1 which appear to indicate (despite marked annual variation and some change in spraying criteria) that the incidence and/or severity of Dothistroma may have increased quite substantially between 1966 and 1986. Is that an indication of decreased forest health?

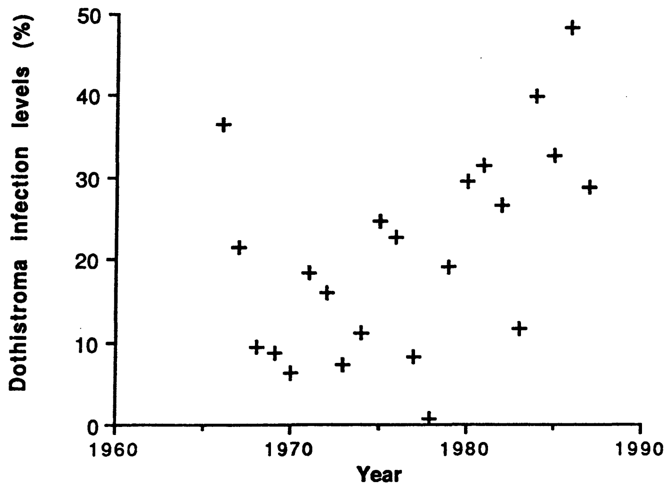

FIG. 1— Plot of Dothistroma infection levels against time. Dothistroma infection level is indicated by the area sprayed for Dothistroma control in any single year expressed as a percentage of the total area of forest aged between 1 and 7 in that year.

There is also some indication from Dothistroma research trials that high levels of one disease can cause increased susceptibility to another. Woollons & Hayward (1984) indicated considerable mortality between ages 4 and 9 in large unsprayed control plots (almost 10 times higher than in comparable annually sprayed plots). A significant agent in the mortality is reported (G. Fry & R. Woollons, pers. comm.) to have been *Armillaria* species.

So I would ask you — could these observations, taken as a whole, imply that our forests are generally more stressed, less thrifty, and more susceptible to disease than they used to be? Wouldn't it be helpful if we had quantitatively monitored forest health since the 1950s to help in answering that question? How should we have done it? Perhaps we could have established permanent forest health plots covering the range range of soils and climates in New Zealand. The use of (say) three plots in different-aged stands at a number of locations could have provided material of a range of ages which could be assessed annually for disease incidence and severity, level of needle retention, and growth rate. Such plots, had they been in place since the 1950s, and been maintained through the rotations, would today provide much of the information we need.

QUESTIONS ARISING

If I am correct in my contention that the health of our plantation forests has declined since the 1950s, there are some consequent questions:

(1) Has the problem arisen because we established a monoculture? Thanks to the publications of Chou (1981), Bain (1981), and Whitehead (1981) I believe that concern on that point has now properly been alleviated. There is, in my view, no evidence that monocultures (provided they maintain a sufficiently broad genetic base) are more at risk than multi-species forests.

(2) Can such a slide be reversed? It is obviously possible that what I am calling a "slide" simply represents the effect of a period of changed weather patterns that, with the next cyclical change, could reverse. It is perhaps more logical, however, to argue that the temperature rise of the developing greenhouse effect may increase the incidence of pathological problems in forests, not reduce the present level. The most recent projections I have seen also indicate substantially increased rainfall levels in the major areas of forest.

(3) Can the present health status of our forests be maintained? While this question again is unanswerable, it is germane to point out that if forest health has declined since the 1950s with what we have regarded as good systems of quarantine, monitoring, R & D, and forest management in place, we should expect to need to improve all of these in the future, if we wish to maintain present health levels.

THE FOREST HEALTH MAINTENANCE SYSTEM

It may be appropriate at this stage to look at the key elements of our forest health maintenance system.

(1) Plant quarantine has been in place since approximately the start of this century and has recently been upgraded with respect to forestry. Is has clearly been successful, both as a deterrent and in terms of interception. Since 1950, an average of more than 500 interceptions of forestry insects have been made each year and perhaps 50 interceptions of fungal material. Despite quarantine, however, an average of 2.2 new species of insects and 2.4 new fungi have become established in plantations each year since 1950. The annual cost to forestry of maintaining New Zealand's quarantine service is $2.14 million.

Considerations of prospects for improving the effectiveness of quarantine must take into account available evidence that some insects, diseases, and seeds have arrived in New Zealand by methods other than human activity.

(2) Forest health monitoring in New Zealand has, since 1956, been largely in the hands of the Forest Biology Survey, renamed the Forest Health Group in 1976. Its current cost is just under $1 million per annum and 96% of its effort goes into plantation forests. A key philosophy behind monitoring has been the prospect that it offers of detection of new pests and diseases early enough to allow containment or eradication. Despite an intensive national coverage for 33 years by well-trained and dedicated staff, some significant pests and diseases have been detected by persons other than Forest Health Officers, and too late to be contained or eradicated.

(3) Research and diagnostic services. Both quarantine and forest health monitoring require diagnostic and research backup, as do the management of outbreaks and the long-term management of pests and diseases. In New Zealand more than $100,000 per annum is currently spent on such services.

(4) Forest managers clearly bear both the direct (e.g., Dothistroma spraying) and indirect (e.g., increment loss) costs of pests and diseases. It may also be argued that there is an opportunity cost - for example, in planting muricata pine (*Pinus muricata* D. Don) rather than radiata pine on sites of high Dothistroma risk and, within radiata pine, in maintaining a broad genetic base for safety reasons. The opportunity cost there is in reduced genetic gain.

Some data exist on these costs. In the 22 years from the summers of 1966–67 to 1987–88 just under 1.2 million ha of plantation have been sprayed at a cost of $13.2 million. The question of increment loss is not straightforward (*see* Appendix 1). Indications are that, provided the background spore load is kept low by chemical spraying, increment loss will be low. For that reason it will not be considered further in this paper.

In contrast, there is no control programme for Cyclaneusma needle-cast and the country-wide annual increment loss figure adopted for this paper has a value of $13.8 million (Appendix 1). Similarly a national cost of $3.6 million per annum has been adopted for the cost of Armillaria root rot (Appendix 1). Losses due to *Diplodia pinea* (Desm.) Kickx, *Sirex noctilio* Fabricius, and other more localised pests and pathogens are undoubtedly significant, but less easily quantifiable.

Integrating the costs under the four headings above suggests a conservative annual cost to New Zealand for forest health of nearly $22 million. This amounts to an annual financial loss of the order of 3.6% (reducing to 3.1% if surveillance, diagnosis, and quarantine costs are excluded) or a loss of some $18/ha/annum, or $2.20/m^3 (*see* Table 1). While this is a substantial sum, it could perhaps be put into perspective by an estimate that the recent re-structuring in the forestry industry will save more than $200 million annually (National Business Review 16.5.89, p. 10).

The calculations did not incorporate opportunity costs and it may be argued that forest managers should, to manage forest health responsibly, incur much greater opportunity costs than they do. Essentially, forest managers in New Zealand expect (with very few exceptions) to plant radiata pine on all their sites, irrespective of

TABLE 1—Estimate* of annual direct and indirect costs associated with health in New Zealand plantation forests

Health factors	Cost ($)
1. Forest health surveillance	931,000
2. Research and diagnostic back-up	100,000
3. Forestry share of New Zealand quarantine costs	2,140,000
4. Spray cost Dothistroma	1,246,000
5. Increment loss Dothistroma	Nil
6. Increment loss Cyclaneusma	13,800,000
7. Increment loss Armillaria	3,600,000
TOTAL	21,817,000

The total cost can also be expressed as:
- An over-all cost (as loss of return) of 3.6%
- A cost of $18.20/ha/year
- A cost of $2.20/m³ wood

* The assumptions on which these estimates are based are presented in Appendix 1.

health. In the short term that has been proven a pragmatic decision, but one must query whether it represents a good long-term strategy. As previously indicated, plantation forest health in New Zealand appears poor by many standards, and traditional understanding (along with some New Zealand trials) would suggest that unhealthy forests are much more vulnerable to further pests and diseases than healthy ones. I would suggest that it is time for forest managers to at least question their "radiata on all sites" approach. In advocating that, however, I am not pre-judging the answer they will obtain. I will, later in this talk, refer to the lack of alternative species to radiata pine and will also explore the significance of the prospect of our "losing" radiata pine as a species altogether.

A BASIS FOR FUTURE DECISIONS

The above review indicates to me that the prospects of maintaining the present level of forest health in New Zealand radiata pine plantations are not good, at least at our present level of financial input. It may thus be appropriate (a) to consider how plantation forestry's expenditure on health compares with that in crop, animal, and pasture farming, and (b) to consider whether an increase in that sum would be feasible and/or sensible.

Costs of expenditure on health expressed as a percentage of the total returns from growing different animal and plant "crops" are given in Table 2. The values range from around 12% for wheat down to 2.4% for beef. Plantation forestry at 3.3% is near the lower end of the scale and is lower than the other plant crops.

While the figures might suggest that by the standards of other crops forestry could afford to pay more to maintain health, the belief that radiata pine on many sites in New Zealand may be marginally economic as an export crop must cause questions as to whether any substantial increase is possible. Additionally, the earlier review of the effectiveness of quarantine and health monitoring did not point to these as being areas in which it would be cost effective to increase expenditure. Forest management however, does, in my view, remain an area which warrants consideration of increased forest health expenditure.

TABLE 2—Annual costs of pests and diseases, expressed as a percentage of the annual returns for different crops*

Crop	Pest/disease cost (%)
Wheat	12.2
Oilseed rape	10.0
Barley	7.2
Rye-grass	5.6
Goats	4.5
Sheep (breeding ewes)	4.4
White clover (seed)	4.1
Dairy	3.6
Plantation forestry	***3.1***
Deer	3.1
Sheep (2-year flock)	2.4
Beef	2.4

* The plantation forestry value comes from this paper. All other values are derived from Lincoln College (1988). For plantation forestry crops the costs include chemical control and loss of increment. For other crops they include chemical control only (which presumably prevents significant loss of value). Surveillance, diagnosis, and quarantine costs are not included.

Before considering either an increased or a modified expenditure on forest health, one should return again to consider future trends in the health of our forests. If a downward trend continues, where will it end up?

Firstly, there is a possibility that it will not continue. Although we tend to accept that pests and diseases are here to stay, there are examples to the contrary. The recent horticultural work in New Zealand, using *Trichoderma* sp. as an *Armillaria* spp. antagonist (Laurenson 1989) may well offer potential for the forest industry as well. FRI's introduction of *Ennogera nassaui* (Girault) to parasitise *Paropsis charybdis* Stål may allow "blue gum" eucalypts to be grown again. Similarly, the work of New Zealand tree breeders has some disease resistance intent. There are good recent examples in the literature of disastrous disease problems being overturned by the use of resistant genetic material - the mycoplasma disease "lethal yellowing" on coconut palms offers one good example of this. There are also prospects from genetic engineering. An insect toxic gene has been sucessfully transferred from *Bacillus thuringiensis* Berliner to tobacco and may offer potential for tree species (Ahuja 1988). It is suggested, for example, that its incorporation might well protect *Larix decidua* Miller against the larch sawfly *Pristiphora erichsonii* (Hartig) and the larch casebearer *Coleophora laricella* (Huebner) (Karnosky *et al.* 1988).

Because new pests and diseases have come in (and presumably will continue to come in) at a rate of more than two a year, however, I believe we need to look further at the prospect that forest health may continue to deteriorate.

To me there are two substantial scenarios that should be explored:

(1) The direct and indirect costs of ill-health of radiata pine will together reach a level such that managers will choose to convert to alternative forestry species (or to an alternative land-use) after logging given areas.

(2) A newly arrived disease, possibly acting on a high base-level of ill health, will cause widespread death of radiata pine over all or many sites.

The probability of either of these scenarios eventually is important to us. While the first might not be too damaging economically, the second (at worst equivalent to the wind-throw of all New Zealand's plantation in the one storm) would impose impossible logistical and marketing problems, with consequent major economic loss. The justification for growing only a single species in plantation forests lies in the argument that the first scenario is more likely than the second. That in its turn is based on the relatively few examples known of wholesale insect- or pathogen-caused death of forests which are not over-mature. Perhaps the worst (and maybe the only?) significant example of such death in a conifer species is that of *Pinus densiflora* Sieb. et Zucc. in Japan, resulting from attack by the pine-wilt nematode *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle.

The probability that the first scenario is more likely than the second will be accepted here, although it should be recognised that this could change with time. As one example, had the pine-wilt nematode and radiata pine not been associated for so long that only resistant radiata pine remain, one might now have to modify those probabilities.

FOREST HEALTH MANAGEMENT AND THE NEXT DECADE

At this point I would like to review the major points I have asked you to accept, and to examine the implications of these for forest health management over the next decade. My contentions are:

(1) That the health of radiata pine in New Zealand has deteriorated significantly over the last 30 years.

(2) That it can be expected to continue to deteriorate.

(3) That (subject to review as new diseases develop) the ultimate outcome is likely to involve us in a move to another forestry species (or another land-use) as compartments reach the end of a rotation - rather than catastrophic mortality.

(4) That because we have no sound database (either sequential or economic) it is not possible to predict the timing of this outcome. There is no sign that it is imminent, and it may be many rotations away.

(5) That increased expenditure on quarantine or forest health monitoring (as carried out at present) is unlikely to substantially modify or delay the outcome.

What should the forest manager and the researcher do at this stage to maintain forest health?

Firstly, and most importantly, I would suggest that those of us who have had the attitude that our plantation resource (which appears to be worth between $2 billion and $12 billion) should be protected at all costs should review this attitude. If my first scenario of gradually increasing ill-health leading to gradual replacement with other species is a valid one, then protection need not be "at all costs". We should reflect that radiata pine is by world standards a relatively low-value species. Such species cannot carry high protection costs and the prospect should exist of replacing them with higher value species.

This does, however, produce one immediate problem. Both the concentration of research on radiata pine over the last 40 years, and the loss to disease of some of our alternative species, have combined to leave us with no obvious alternative species to radiata pine. Some of you will know that I have spent the last decade arguing that research into selection, siting, and establishment of alternative species to radiata pine is vital to ongoing New Zealand plantation forestry. For different reasons the NZ Farm Forestry Association also seeks such research. Both of us have been unsuccessful in our calls, but if my arguments above are correct, such species will be needed, sometime, and research into them is properly to be regarded as a charge against forest protection. It will not escape your notice that alternative species of higher value than radiata pine can, in their turn, carry higher protection costs.

The other "background" job which is necessary has already been alluded to. New Zealand must develop a database from which to measure changes in forest health and allow forward prediction. It must be able to place such changes into economic as well as biological perspective so that forest managers know when and on which sites radiata pine is becoming uneconomic to grow for health reasons.

I also foresee the next decade as being a period in which much of the responsibility for forest health monitoring will pass from the Forest Health Group to the forest manager as forest health becomes increasingly seen as just another silvicultural component affecting profitability, rather than an issue which may make or break the sector. That is where it properly belongs.

I envisage forest management staff doing their own forest health checks. They will need additional education (possibly funded through some re-direction of the present forest health surveillance budget). The staff may also need incentives to ensure that they always make the effort to go and examine an inaccessible patch of dead trees. (While these incentives are likely to be financial — e.g., a reward for the first reporting of a new insect pest or disease — rewards should not be at a level where staff will be tempted to import their own diseases!) Management staff will still need servicing by FRI and by Forest Health Officers.

The resultant increased forest health awareness and level of recorded data will aid managers in making appropriate species choice, disease control, and silvicultural decisions. Existing stand models certainly allow some approximations as to the impact of disease (e.g., by reducing site index). As the level of the database improves, so can the quality of decision making.

The pressure on FRI will, I predict, be:

(a) To assist in designing and annually assessing a quantitative system to monitor the over-all levels of health in our forests over time;

(b) To develop stand and estate models into which disease level information can be plugged effectively;

(c) To research alternative species to radiata pine.

In the current economic climate, I suspect that these developments will happen only if industry sees them as proper costs of forest health and forest protection, and is prepared to pay for them accordingly.

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APPENDIX 1

BASIS FOR MATERIAL IN TABLE 1

All costing assumes a forest with a normal age-class distribution.

Items 1, 2, & 3: D. Kershaw, Ministry of Forestry, pers. comm.

Item 4: Mean cost of spray programme in years 1980–87 inclusive (R. Blair, Ministry of Forestry, pers. comm.)

Item 5:
Dothistroma — Van der Pas, Bulman & Horgan (1984) indicated that, in a background situation where copper oxychloride spraying of stands with Dothistroma infection of 25% or more is regular (i.e., where spore loads are being kept relatively low), the volume loss in unsprayed forest may amount to only some 15 m^3/ha at age 30, or 0.5m^3/ha/annum. As spraying in diseased forest in New Zealand is routine, the conservative assumption has been made that the volume loss due to Dothistroma is nil.

Item 6:
Cyclaneusma — Van der Pas, Bulman & Slater-Hayes (1984) estimated the annual increment loss over the New Zealand forest estate as 2.3%. Bulman (1988) estimated 5% increment loss per annum in stands aged between 6 and 20 years, which crudely approximates over the rotation to van der Pas, Bulman & Slater-Hayes' 1984 estimate. Annual increment for New Zealand plantations (based on 1.2×10^6 ha and MAI of 25 m^3/ha) = 30×10^6 m^3; 2.3% of this = 690 000 m^3 × \$60/m^3 = \$$41.4 \times 10^6$. No allowance was made by van der Pas, Bulman & Slater-Hayes for compensatory growth by healthy trees in a stand where healthy and diseased trees are mixed. Maximum increment loss is in the 11- to 20-year age-classes (Bulman 1988) by which time forests managed under a sawlog regime are at final-crop stocking. Thus there would be little compensation. Despite that, van der Pas, Bulman & Slater-Hayes' figures have been divided by 3 to allow for this factor, and for regional variation in Cyclaneusma incidence. Annual loss figure chosen, \$$13.8 \times 10^6$.

Item 7:
Armillaria — MacKenzie (1987) suggested that a loss of between 6% and 13% of potential volume is likely in a 28-year sawlog regime on a native cutover site. On the sites he assessed, a 6% loss approximated to 1 m^3/ha/annum. Assuming that only 5% of New Zealand forests (= 60 000 ha) are susceptible, the increment loss = 60 000 m^3 which at \$60/m^3 = \$3.6 million/annum. There are undoubtedly also extra site preparation costs on Armillaria-prone sites, but these have not been estimated

Other data used

Area of New Zealand plantation forest 1.2 million ha (Ministry of Forestry 1989). Annual harvest from plantation forests 10 million m^3. Value of 1 m^3 harvested wood \$60 (van der Pas, Slater-Hayes, Gadgil & Bulman 1984).