CYCLANEUSMA NEEDLE-CAST
in New Zealand

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CYCLANEUSMA NEEDLE-CAST IN NEW ZEALAND

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(Editors)

forest research

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ACKNOWLEDGMENTS

SUMMARY

The ascomycetous fungus, *Cyclaneusma minus*, has been experimentally shown to be able to infect *Pinus radiata* plants older than about 3 years of age (temperature range tested: 10° to 25°C). In susceptible trees, infection by the fungus leads to disease, which is characterised by premature casting of 1-year-old or older needles, mainly in spring but also, to a lesser degree, in autumn. Cast needles are usually a mottled yellow-brown in colour. Apothecia (fruiting bodies) of *C. minus* are produced on the needles lying on the forest floor and the greatest number of apothecia per unit area were produced in autumn-winter (May to August). Ascospores of *C. minus* contained in the apothecia are forcibly ejected and become airborne after a period of rain. These airborne ascospores were trapped throughout the year but were most numerous during the autumn-winter months. Current season's needles were resistant to infection by the ascospores until they were about 8 to 9 months old and *C. minus* was first isolated from these needles in autumn-early winter (May to June). Most of the infected needles were shed when they were about a year old. At least two morphologically distinct types of *C. minus* were found in the New Zealand population but whether these morphological differences reflect differences in pathogenicity is not yet known.

Aerial surveys of forests throughout New Zealand showed that severity of the needle-cast was highest in 11- to 20-year-old stands and lowest in the 1- to 5-year-old and over 25-year-old stands. Northland, Auckland, Waikato, Bay of Plenty, Taupo, Gisborne, Dunedin, and Southland biological regions had a high incidence of the disease. The disease incidence was very low in Nelson, central Otago, and Canterbury. In all regions, microsites, particularly those at high altitudes, also had a high incidence of disease. The relationship between disease severity (expressed as percentage of the green crown showing symptoms of the disease) and growth was studied by carrying out a complete stem analysis of 20 pairs of healthy and diseased trees at age 15 years. The pairs were selected when the trees were 9 years old and disease severity was recorded annually. There was a reduction of approximately 60% in average volume increment at an average disease severity of 80%. Trials, carried out to establish the relationship between diameter increment and disease severity in different parts of the country, showed that an average disease severity of 60% over 6 years resulted in a 50% loss in diameter increment. Projections of stand growth to age 30 for various proportions of diseased trees (mean disease severity of affected trees: 60%) predicted a reduction in volume of 10–14 m^3/ ha for each 10% increase in the proportion of diseased trees. For the country as a whole, growth loss of 6.6% per annum for the *P. radiata* estate aged between 6 and 20 years was predicted. The corresponding financial loss was estimated to be of the order of $51 million per year.

A fungicide screening trial showed that fortnightly applications of dodine or injection with carbendazim were able to control the disease. Two aerial applications of carbendazim a month apart gave no control, but monthly aerial applications of dodine for 6 months gave appreciable control. The cost of such measures was not economically justifiable. Silvicultural trials showed that stocking density and pruning had no effect on disease incidence or severity. Trials carried out to test the effect of applying five different thinning ratios at five different crop ages showed that, using susceptibility to the needle-cast as a main criterion for tree selection, a delayed first thinning at age 7 or 8, followed by a second thinning at age 10 succeeded in achieving an almost disease-free final crop stand.

INTRODUCTION

Cyclaneusma needle-cast has been reported from all continents as a serious disease of many *Pinus* species (Millar & Minter 1980). In New Zealand, periodic, severe, abnormal casting of 1-year-old and older needles of *Pinus radiata* D.Don, which is characteristic of Cyclaneusma needle-cast, was reported in 1952, 1956, and 1962 (Gilmour 1966) and more recently in 1974, 1975, 1981, 1982, 1985, 1988, and regularly in the 1990s in various localities (Bulman 1995; Forest Research Institute, unpublished records).

Both the name of the disease and the names of the fungi causing it have changed during the relatively long period over which the disease has been known. The following explanation about these name changes may be of help to the reader.

In New Zealand, Gilmour (1959) was the first to recognise the close association of a fungus (then known as ***Naemacyclus niveus*** (Persoon:Fries) Saccardo) with the periodic abnormal needle-cast. The disease then became known here as **Naemacyclus needle-cast** and this is the name used in all publications and reports up to 1983.

Butin (1973) recognised that there were two host-specific species of *Naemacyclus* on *Pinus* spp. and created a new species *Naemacyclus minor* Butin for the fungus found on *P. radiata* and five other *Pinus* species. It had been realised for some time (Korf 1962) that the application of the generic epithet *Naemacyclus* to *N. niveus* was nomenclaturally inaccurate but there was a general reluctance to change a name which had become familiar. The mistake was finally corrected when DiCosmo *et al*. (1983) erected a new genus *Cyclaneusma* (an anagram of *Naemacyclus*, to maintain familiarity) to accommodate *N. niveus* and the similar *N. minor*. The current names thus are ***Cyclaneusma niveum*** (Persoon:Fries) DiCosmo *et al.* and ***Cyclaneusma minus*** (Butin) DiCosmo *et al.* The disease is now known as **Cyclaneusma needle-cast**. In New Zealand, *C. niveum* is recorded on *Pinus coulterii* D.Don and *C. minus* on *P. radiata* and *P. strobus* Linnaeus.

Over the last 25 years, members of the Forest Health Group at the New Zealand Forest Research Institute have carried out a considerable amount of work on Cyclaneusma needle-cast. Much has been published and the more recent work has been documented but not published. The aim of this Bulletin is to bring together all work carried out in New Zealand on Cyclaneusma needle-cast. Chapters 1, 2, 4, 5, and 7 are wholly or partly based on previously published work.

Part I deals with the biology of the fungus. This knowledge is fundamental to the planning of control strategies and in understanding the interaction between climate and the disease. The standard mycological terms used in this part may not be familiar to everyone and they are explained in the Glossary. Those who are not interested in this background information may prefer to go Parts II and III which deal with the effect of the disease on the tree crop and with the methods of control, respectively.

Cyclaneusma needle-cast is a disease of complex aetiology and the interactions between host genotype and, particularly, host nutrition and the variable fungal population are not fully understood. Much work on these aspects remains to be done.

PART I:

BIOLOGY OF THE PATHOGEN

1. SYMPTOMS AND PATHOGENICITY

P. D. Gadgil

(adapted from P.D.Gadgil 1984: *New Zealand Journal of Forestry Science 14*: 179–182)

Abstract

Symptoms and signs of Cyclaneusma needle-cast are described. In a pathogenicity trial, rooted cuttings of three clones taken from 7-year-old trees and seedlings of *Pinus radiata* were inoculated with ascospores and macerated mycelia of *Cyclaneusma minus* and kept for 3 months in growth rooms at different temperatures. All cuttings belonging to two clones exhibited typical symptoms of the disease and the fungus was reisolated from needles taken from these cuttings. Both types of inocula were effective. Needles from cuttings of the third clone yielded very few isolates of *C. minus* and they did not show any symptoms of the disease. Seedlings were not infected by the fungus. It was concluded that *C. minus* is pathogenic to older plants but not to seedlings of *P. radiata*.

1.1 SYMPTOMS

The characteristic symptoms and signs of Cyclaneusma needle-cast are:

(1) Premature needle-cast in spring and autumn. The needle-cast in spring is more severe than that in autumn. One-year or older needles in the central and lower parts of the crown turn first a mottled yellow-green (Fig.1.1) and then a mottled yellow-brown a few weeks later. Almost the whole crown may be affected in highly susceptible trees (Fig.1.2). Transverse reddish-brown bands are also commonly seen (Fig.1.3). Needles showing such symptoms are readily detached from the tree and most are shed prematurely, generally in September and October. In colder parts of New Zealand, the needle-cast may occur a little later. In some years and in some localities, the needles finally become a uniform reddish-brown rather than the more usual mottled yellow-brown. By December, all affected needles are usually shed and the crown looks very thin, holding only the newly flushed foliage (Fig. 1.4). In contrast, resistant trees may hold foliage up to 3 years old.

The autumn needle-cast occurs from April to June. One-year or older needles are affected and the symptoms are similar to the spring needle-cast. The severity of the needle-cast varies from year to year.

(2) Newly flushed needles are resistant to infection up to about 8–9 months of age and remain green.

(3) Susceptibility of trees to infection is very variable and stands usually contain a mixture of susceptible trees, recognisable in spring by their yellow/brown crowns, and resistant trees with green crowns (Fig.1.5 and 1.6).

(4) Needles lying on the ground bear numerous apothecia (fruiting bodies) of *Cyclaneusma* (Fig.1.7). These apothecia are roughly rectangular in appearance when partially open and elliptical when widely open. They are waxy, reddish-brown when young and later become the same colour as the needle surface, and are 0.1–0.65 (mostly 0.3–0.35) mm long and 0.20–0.25 mm wide. As they develop, the apothecia push through and tear the needle epidermis across the ends but it remains hinged along the sides. When the apothecia are mature, they swell when moist and the half-lids formed by the hinged epidermis are pushed back, exposing the slightly convex, straw-coloured, spore-bearing layer. Apothecia are very rarely found on needles before they are shed but develop readily on fallen needles.

FIG. 1.1 – Yellowing 1-year-old foliage of a highly susceptible tree

FIG. 1.2 – *Pinus radiata* **with severe Cyclaneusma needle-cast**
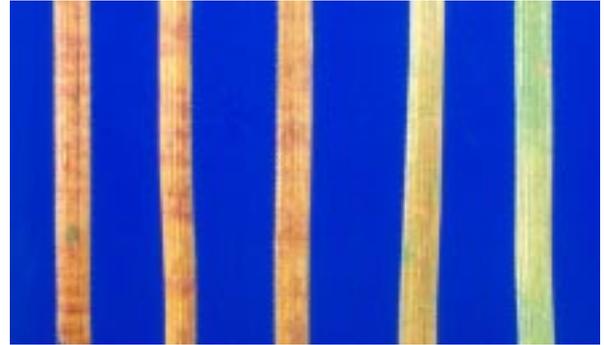
FIG. 1.3 – *Pinus radiata* **needles with the bands typical of** *Cyclaneusma* **sp. infection**

FIG. 1.4 – **Trees that have suffered severe Cyclaneusma needle-cast. Note the thin crowns and absence of 1- and 2-year-old needles**

FIG. 1.5 – **Susceptible trees scattered among unaffected trees**

FIG. 1.6 – **Two trees that are susceptible to Cyclaneusma needle-cast growing among unaffected trees**

FIG. 1.7 – *Cyclaneusma* **apothecia (fruiting bodies) on** *Pinus radiata* **needles**

1.2 PATHOGENICITY

The study described below was carried out to determine whether or not *Cyclaneusma minus* was able to infect living, healthy needles of *Pinus radiata.*

Methods

Plant material

Rooted cuttings of three clones of *P. radiata*, taken from 7-year-old trees and grown for 2 years in a glasshouse, and 2.5-year-old glasshouse-grown seedlings of *P. radiata* were used. The clonal material was not specially selected but was available as surplus from an unrelated trial, and the seedlings were grown from commercial seed.

Inoculum

The inoculum of *C. minus* was of three types:

(1) Ascospores from apothecia produced naturally on needles of *P. radiata*;

(2) Ascospores from 4-week-old cultures grown on 3% malt agar;

(3) Macerated mycelium harvested from 4-week-old liquid shake cultures in 3% malt.

There were between 70 000 and 90 000 ascospores/ml in both Type 1 and Type 2 inocula.

Inoculation

In February 1976, 12 cuttings of each clone and 24 seedlings were each sprayed with 20 ml of one inoculum type (a total of 36 cuttings per clone and 72 seedlings were inoculated) and the plants were then placed in four growth rooms maintained at different temperatures and vapour pressure deficits (Table 1.1). Each growth room was assigned three cuttings per clone and six seedlings sprayed with each inoculum type, and an equal number of unsprayed cuttings and seedlings. The plants were misted for 4 days after inoculation and the misting intervals were so arranged that the foliage remained moist without appreciable run-off. After the misting period the plants were watered as required.

After 96 days in the growth rooms the plants were taken to the laboratory. Twenty, 1-year-old or older, apparently healthy needles were chosen randomly from each plant, surface sterilised, then cut into approximately 1-cm segments, placed on 3% malt agar in petri dishes, and incubated at 20°C.

Results

By the end of the experiment yellow-brown mottling, typical of the needle-cast, was apparent in many of the older needles belonging to two of the three clones. All needles on cuttings of the third clone, the seedlings, and the control plants showed no symptoms of ill health. There was no premature needle fall. Needles of the two clones that showed yellowing yielded cultures of *C. minus*, while only a few isolates of the fungus were obtained from the symptomless needles of the third clone (Table 1.2). The seedlings and the control plants did not yield

TABLE 1.1 – Conditions in growth rooms.

Growth room	Temperature (°C ± 0.5°C)		Vapour pressure deficit (mb)		Light intensity (W/m^2)	Photoperiod (hours)
	Day	Night	Day	Night		
1	20	12	2	2	140	16
2	25	15	8	5	150	14
3	15	10	8	5	146	14
4	25	20	8	5	132	14

TABLE 1.2 – Number of isolates of *C. minus* per 10-cm needle length. Results from plants inoculated with different inocula have been pooled.

	Growth room			
	1	2	3	4
Clone X	3.1	3.4	2.9	2.8
Clone Y	3.2	2.2	2.4	3.0
Clone Z	0.1	0.004	0.08	0.1
Seedlings	0.0	0.0	0.0	0.0
Controls	0.0	0.0	0.0	0.0

any *C. minus*. No differences attributable to inoculum type or growth room conditions were found. The results showed that *C. minus* was pathogenic to some adult plants of *P. radiata* but not to the 2.5-year-old seedlings tested.

Discussion

There have been conflicting reports about the pathogenicity of *Cyclaneusma* (*Naemacyclus*). Peace (1962) reported that, although *N. niveus* occurred on fallen needles of *P. sylvestris* in Britain, it had not been associated with defoliation. Benito Martinez & Torres Juan (1965) considered that *N. niveus* could be a parasite but was generally present as a saprophyte. According to Pawsey (1967), *N. niveus* was common on fallen needles of *P. radiata* in Australia and it was apparently largely saprophytic in nature. Stahl (1966), however, thought that *N. niveus* might be the cause of a serious needle-cast in the Australian Capital Territory. In North America, Darker (1932) reported

that *N. niveus* caused needle-casting in pines, and Hepting (1971) stated that, of the needle fungi on *P. radiata*, "*N. niveus* is probably the most widespread and damaging".

The pathogenicity trial described here showed that *C. minus* caused the symptoms held to be typical of Cyclaneusma (Naemacyclus) needle-cast on *P. radiata* in day/night temperatures varying from 25°/20°C to 15°/10°C with 4 days of leaf wetness, that all types of inocula were equally effective, and that the seedlings tested (<3 years old) and some adult plants of *P. radiata* were resistant to infection by *C. minus*. These results, the work of Karadzic (1981), and the supporting evidence of Kistler & Merrill (1978) show that *C. minus* is pathogenic to *P. radiata* and *P. sylvestris*. The finding that young seedlings used in this experiment and some individuals of *P. radiata* were resistant to infection by *C. minus* may serve to explain the inconclusive results of past pathogenicity tests (e.g., Magnani 1972).

2. ASCOSPORE PRODUCTION, DISPERSAL, AND INFECTION

P. D. Gadgil

Abstract

Samples of needles cast in a 10-year-old stand of *Pinus radiata* were collected over fortnightly periods and the numbers of spore-bearing apothecia present in the litter layer were determined. There were two peak periods of needle cast — a major one in spring and a minor one in autumn. The greatest numbers of apothecia were found in autumn-winter (May to August). Records from a Hirst spore trap set up in the same stand showed that airborne ascospores of *Cyclaneusma minus* occurred most frequently in autumn-winter and that ascospore release was dependent on rainfall. Monthly isolations from needles showed that current season's needles were first colonised by *C. minus* in autumn-winter (May-June) when they were about 8 to 9 months old and by *Lophodermium* spp. about 2 months later. Most of the infected needles were shed when they were about 1 year old but some were retained until the following winter.

2.1 ASCOSPORE PRODUCTION AND DISPERSAL

The aim of this work was to follow the development of apothecia of *C. minus*, to estimate the numbers of ascospores present in the air, and to follow the progress of infection of *P. radiata* needles by the fungus.

Methods

Experimental site

A small plantation (0.4 ha) of trees of four clones (A, B, C, and D) of *P. radiata* was used for this study. This plantation occupied part of a large level area in Whakarewarewa Forest (near Rotorua) devoted to clonal and provenance trials. It was established in 1968 and had been thinned to about 500 stems/ha. The trees were 10 years old and about 15 m tall when the study began. Trees of all four clones were known to have shown symptoms of premature needle-cast and two of the clones (A and B) had been particularly susceptible to the disease in the past. There was little understorey vegetation and the litter layer contained numerous needles bearing apothecia of *C. minus*.

Estimation of numbers of apothecia

Apothecia of *Cyclaneusma* are rarely found on living needles, but they usually develop on fallen dead needles (Rehm 1896; Dennis 1978). Observations have shown that *C. minus* on *P. radiata* behaves similarly in New Zealand. The litter layer is therefore the main source of ascospores. The following procedure was adopted to estimate the number of spore-bearing apothecia present on the litter layer throughout the year.

Three rectangular litter traps were placed about 20 m apart under trees of clones A and B. Trapped litter was collected fortnightly from 11 October 1978 until 13 February 1980. Spore-bearing apothecia of *C. minus* on 10 randomly selected needles were counted and the fresh weight of the total catch was recorded. A small sample of litter (about 10 g fresh wt) was removed, weighed, oven-dried, and weighed again to determine the amount of water present. The number of needles in this sub-sample was counted. From these data the total number of needles trapped in that fortnight was calculated. The remaining litter was then taken back to the experimental site and placed in a wooden frame, which rested on the litter layer but was separated from it by a layer of nylon mesh. The frame was covered with nylon to prevent ingress of additional needles. After the first fortnight, in addition to collecting needles from the litter traps, the needles exposed in the preceding fortnight(s) were also collected and taken to the laboratory. The number of spore-bearing apothecia on 10 needles from each collection was counted and the samples were returned to the appropriate frames. Each collection was examined every fortnight until no sporulating apothecia of *C. minus* had been found for two consecutive fortnights.

The first fortnight for which an estimate of the total number of spore-bearing apothecia of *C. minus* present on the litter layer could be made was the last fortnight (31 January to 14 February 1979) in which apothecia were found on the first collection (made on 25 October 1978). The number of apothecia in a collection for a fortnightly period was estimated by multiplying the average number of apothecia per needle by the estimated number of needles per square metre in that particular collection. The total number of apothecia present was obtained by adding together the numbers of

apothecia in all the collections still bearing viable apothecia on that particular date. For example, the total number of apothecia present between 31 January and 14 February 1979 was obtained by adding the numbers of apothecia in collections made on 25 October, 8 November, 22 November, 6 December, 3 January, 17 January, 31 January, and 14 February.

Spore trapping

A Hirst spore trap was located in the middle of the plantation. Airborne particles were trapped on a strip of transparent positive film that was lightly smeared with petroleum jelly. Airflow was adjusted to 10 litres/minute. The sampling period ran from May 1977 to October 1979 (30 months) with an unfortunate break of 9 weeks from 22 March to 25 May 1979 because of frequent motor failures. Hourly temperature and rainfall data were obtained from an official Meteorological Service climatological station sited 1 km from the spore trap. Each exposed collecting strip was cut in sections representing successive 24-hour periods (starting at 2 p.m. on Wednesday) and mounted on microscope slides. The entire surface was scanned under a low power (10×) objective and the number of *Cyclaneusma* ascospores seen on 2-mm sections (corresponding to exposure for 1 hour) was recorded.

Results

There were two peak periods of needle-cast — spring (October-November 1978, September-December 1979) and autumn-early winter (April-June 1979) (Fig. 2.1). The period over which the needles bore sporulating apothecia varied from 24 weeks (needles collected on 14 March) to 6 weeks (collected on 15 August and 10 October) with a mean of 10 weeks. No major seasonal variation in the length of the fruiting period was found except that four collections made in the spring (two in 1978 and two in 1979) did not produce any apothecia for about a fortnight after collection. All other collections contained needles bearing *C. minus* apothecia and, as apothecia were not seen on needles still on the trees, it is assumed that these fructifications were produced in the period which elapsed between needle fall and needle collection, a maximum of 14 days. Usually, the number of apothecia per needle increased with time for two to three fortnights after needle cast and then decreased. There was a seasonal trend in the number of apothecia present — in decreasing order the ranking was autumn (up to 75 apothecia per needle), winter (up to 70), spring (up to 30), summer (up to 20).

Estimates of the total numbers of spore-bearing apothecia for fortnightly periods for a year are given in Fig. 2.2. The large numbers of apothecia present
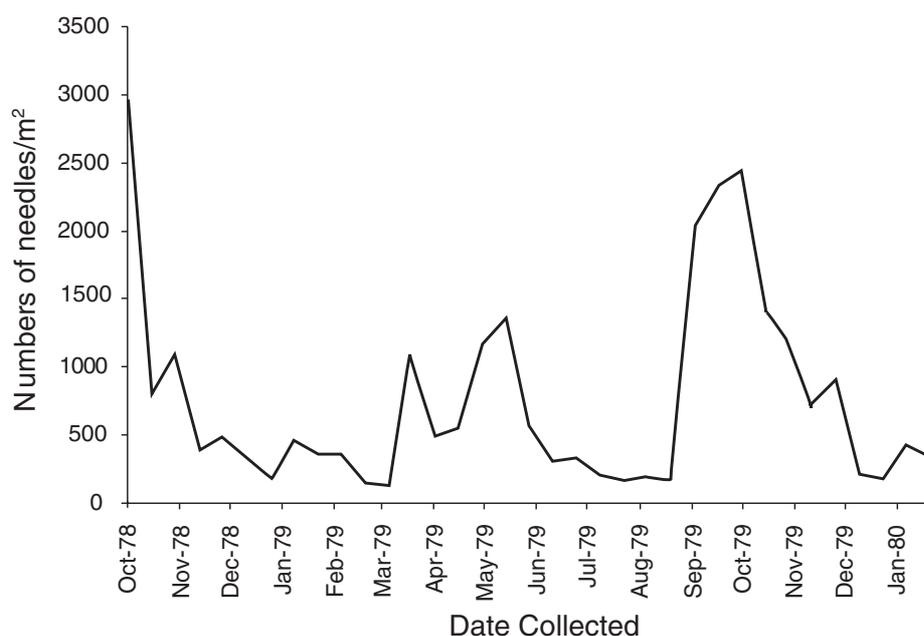
FIG. 2.1 – Numbers of needles per square metre collected every fortnight from 25 October 1978 to 13 February 1980.

from 11 April to 1 August were the result of prolific fruiting body production on the large number of needles cast in autumn-early winter (Fig. 2.1). The smaller November peak reflects the heavy spring needle fall with fewer apothecia per needle than on needles cast in autumn. Spore trap records for a part of this time were also available and are included in Fig. 2.2. There is a gap in the records, but the spore numbers peaked in winter, as did the numbers of apothecia.

Cyclaneusma ascospores were trapped throughout the year but there was a marked seasonal variation in the number of ascospores trapped. In Fig. 2.3 the frequency of trapped ascospores is expressed in terms of the proportion of the number of hours in a month in which ascospores were trapped to the total number of hours in that month. The major peaks in spore catches were in autumn and winter (May, June, July 1977; April-July 1978; June, July, August 1979). From September 1977 to March
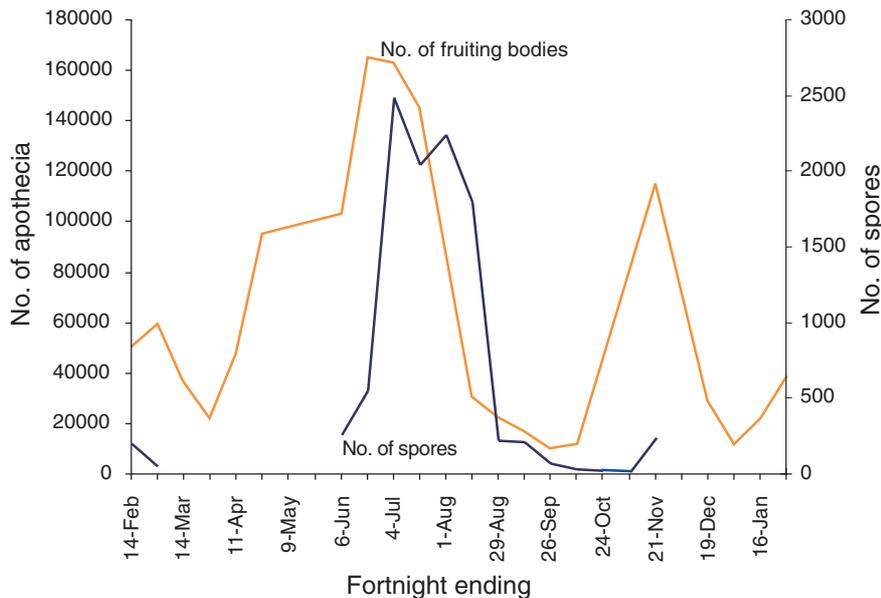
FIG. 2.2 – Total numbers of sporulating apothecia of *C. minus* present per square metre of the litter layer and the numbers of *Cyclaneusma* ascospores caught in a Hirst spore trap for fortnightly periods (February 1979 to January 1980). The gap in the spore numbers data occurred because the trap was out of action.
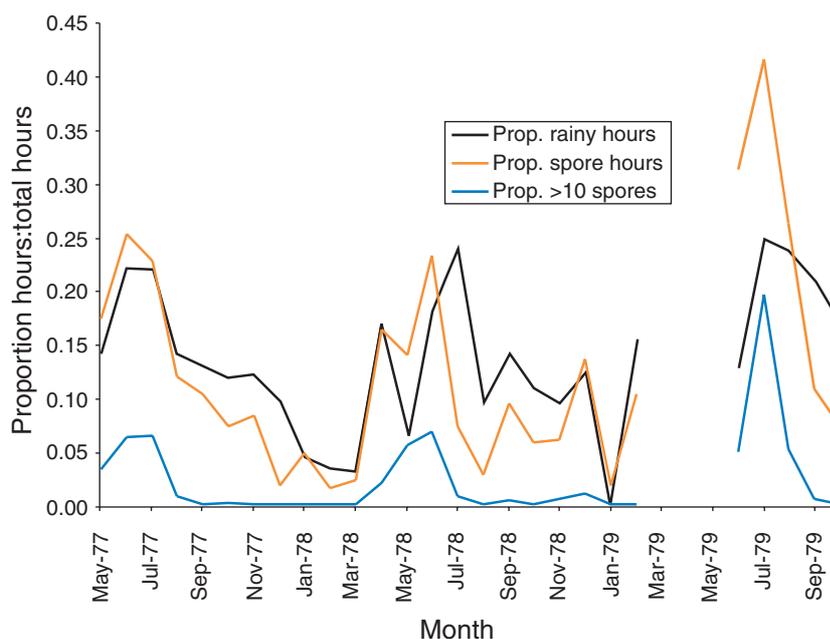
FIG. 2.3 – Frequency of occurrence of *Cyclaneusma* ascospores and the frequency of rainfall. An hour with more than 0.1 mm rain is regarded as rainy. Solid squares = proportion spore hours : total hours; open circles = proportion hours >10 ascospores : total hours; solid diamonds = proportion rainy hours : total hours.

1978 there were no hours in which more than 10 ascospores were caught and in the spring and summer of 1978–79 September, November, and December were the only months when more than 10 ascospores in some hours were trapped (Fig. 2.3, open circles). There was a significant correlation (p <0.01) between frequency of occurrence of ascospores and frequency of rainfall (expressed as the proportion of rainy (>0.1 mm) to total hours). The relationship between spore release and rainfall was further explored and it was demonstrated that the maximum effect of rain on spore release occurred in the fifth hour after the commencement of rainfall. The effect of rainfall was modified by season and generally, although the same frequency of rainy hours yielded the same frequency of spore hours throughout the year, a given amount of rainfall produced a greater spore count in autumn. The greater numbers of spore-bearing apothecia of *C. minus* during this period (Fig. 2.2) presumably account for this effect.

2.2 INFECTION PERIODS

The aim of this work was to determine when infection of needles of *P. radiata* occurred.

Methods

The experimental site described in the previous section was also used for this work. Five trees each of two clones (A and B) which were known to he particularly susceptible to premature needle-cast were selected. Clone A trees usually showed the symptoms about a month earlier than trees of clone B. Five branches in the lower crown of each tree which could be reached from the top rung of a 4.25-m ladder were tagged. In the first week of each month, one needle of the current season's growth and one needle of the previous season's growth were picked from each tagged branch. Collections were begun in November 1977 when the current season's needles were about 2 months old and the previous season's needles about 14 months old. Only living needles that had not formed an abscission layer were collected. The last collection was made in August 1979.

In the laboratory the length of each needle was recorded. Each needle was surface-sterilised and cut in approximately 1-cm segments. The segments were placed on 3% malt agar in petri dishes and incubated at 20°C. All fungi growing out from the needle segments were recorded.

Results

Cyclaneusma minus colonies grew readily from the cut ends as well as from the undamaged sides of the needle segments. The appearance of *C. minus* colonies was easily recognisable, although there was considerable variation in colony texture and colour. Species of *Lophodermium* were also commonly isolated. These, unfortunately, could not be identified to species level. Two species of *Lophodermium* from pines have been described in New Zealand (Johnston 1992), and there is a possibility that more are present. *Lophodermium seditiosum* Minter *et al.*, the species shown to be pathogenic to *Pinus* spp. (Minter & Millar 1980), does not appear to occur here. Other fungi (species of *Strasseria, Neurospora, Sclerophoma, Cladosporium, Cephalosporium, Phomopsis, Chaetomium, Pestalotia, Hendersonia*, and unidentified species) were also isolated but no particular species appeared as frequently or as consistently as *C. minus* or *Lophodermium* spp.

The pattern of colonisation of needles by *C. minus* and *Lophodermium* spp. was similar in both clones except that trees of clone B lagged 1–2 months behind clone A. In 1977–78 neither fungus was isolated from current season's needles (flushed 1977) for the first 6 months. Isolates of *C. minus* first began to appear in late autumn-early winter (May-June). The number of isolates of *C. minus* per unit length of needle increased rapidly after this until September- October 1978 and then remained at a high level. Infection by *Lophodermium* spp. lagged behind that by *C. minus* by 1–2 months but showed a similar trend (Fig. 2.4). Many needles showed the typical yellow-brown mottling associated with the needle-cast and were shed in September-October 1978 when they were about a year old, but some needles were retained and the last needles of the 1977 flush were cast in May-June 1979 (20–21 months old) by which time they were extensively colonised by both *C. minus* and *Lophodermium* spp. The pattern of colonisation of needles that flushed in 1978 was similar to those of the previous year, except that the *C. minus* numbers were lower.

The needles which were already over a year old when sampling began in November 1977 were
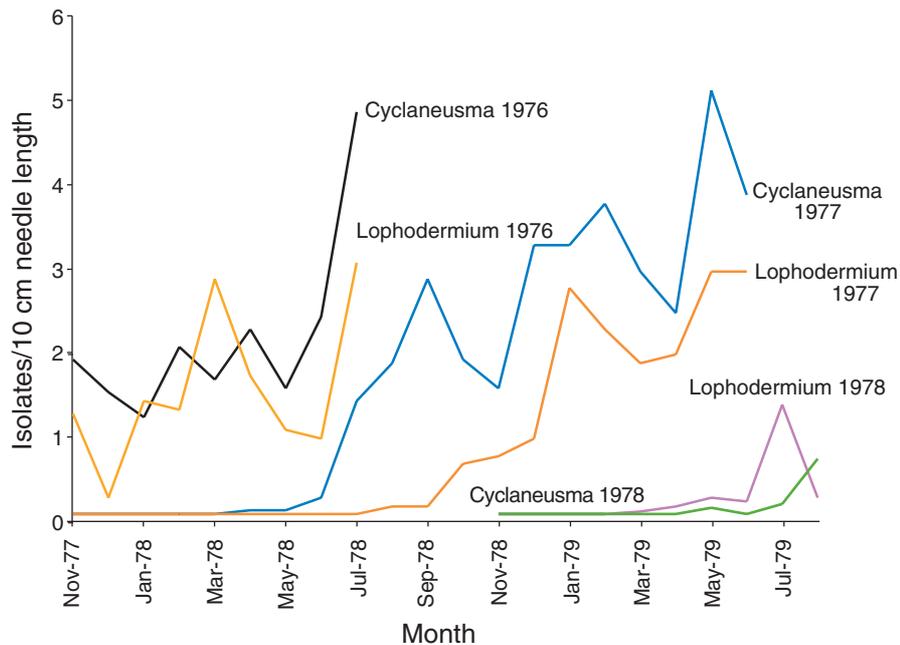
Key:

Cyclaneusma minus	1976 needles,	14 – 22 months old
Lophodermium spp.	1976 needles,	14 – 22 months old
C. minus	1977 needles,	2 – 21 months old
Lophodermium spp.	1977 needles,	2 – 21 months old
C. minus	1978 needles,	2 – 11 months old
Lophodermium spp.	1978 needles,	2 – 11 months old

FIG. 2.4 – Numbers of isolates of *C. minus* and *Lophodermium* spp. per 10-cm needle length from clone A. The data are for needles which flushed in August-September 1976, 1977, and 1978. Sampling began when the 1976 needles were 14 months old; it covered the full lifespan of the 1977 needles and the first 12 months of the 1978 needles. No data are presented for the first 2 months after needle-flush for the 1977 and 1978 needles, as they were then too short to be sampled.

colonised by *C. minus* and *Lophodermium* spp. at that time and supported a fluctuating but moderately high *C. minus* population which showed a sudden increase in June-July 1978, just before the last needles were cast.

Discussion

This study showed that the frequency of occurrence of *Cyclaneusma* ascospores in the air was related to periods of rainfall. This effect of rainfall is well known for many ascomycetes (Ingold 1971) and has been recorded for *Naemacyclus* (Pawsey 1967). Over the period of this study, rain was frequent and did not appear to be a factor which would limit spore release. The time of the year when the largest number of apothecia were present was, as expected, the time when ascospores were most frequently trapped and when most of the infection occurred. There were two peak periods of needle-cast and, of

the two, the needle-cast in spring was the heavier. Most of the needles cast in the spring were just over a year old and were shed prematurely, almost certainly as a result of infection by *C. minus*. It might have been expected that the largest total number of apothecia would therefore be found in spring. But the needles cast in spring had fewer apothecia than the needles which fell in autumn-winter and although the total number of cast needles was greater in spring, the total number of apothecia was less. A possible explanation is that the spring-cast needles had been exposed to only one infection and therefore had lower *C. minus* populations than the needles which were cast the following autumn-winter and had been exposed to two infection periods (Fig. 2.4).

In the central North Island of New Zealand infection by *C. minus* was first recorded in late autumn-early winter. Merrill, Kistler, Zang, & Bowen (1980),

working in Pennsylvania, United States, with *P. sylvestris*, recorded one major infection period in spring and two minor infection periods in summer and autumn-early winter. In New Zealand the needles were about 8–9 months old when isolates of *C. minus* were first obtained, whereas in Pennsylvania first infection occurred when the needles were fully expanded (about 5 months old) and the major infection took place when the needles were 12–13 months old. Rack (1981), working on the colonisation of *P. sylvestris* needles by *Cyclaneusma* and *L. seditiosum*, found that in Germany *Cyclaneusma* was first isolated from the current season's needles in late autumn when they were about 6 months old and the number of infections increased until the needles were about 1 year old, a pattern very similar to that found in this study. The isolation chronology with *L. seditiosum* was, however, the reverse of that of *Lophodermium* spp. in New Zealand. *Lophodermium seditiosum* was first isolated from 3-month-old needles in summer, well before *Cyclaneusma* made its first appearance. In New Zealand *Lophodermium* spp. lagged 1–2 months behind *C. minus*, which suggests that they are secondary colonisers rather than primary pathogens here, or that they sporulate later. Rack (1981) also reported that when needles were plated *Cyclaneusma* colonies nearly always grew out only from the cut ends. In this study no such trend was found and the needle segments frequently had *Cyclaneusma* colonies growing out of the sides as well as the cut ends. These differences in behaviour may be accounted for by climatic differences, or they may indicate that either *P. sylvestris* needles are more susceptible to *Lophodermium* infection or that *L. seditiosum* is a more aggressive pathogen of *P. sylvestris* than the *Lophodermium* spp. present in New Zealand are of *P. radiata*. Minter & Millar (1980) considered *L. seditiosum* to be the most pathogenic *Lophodermium* species. Whatever the minor differences, all studies agree that *Cyclaneusma* is not isolated from young needles (<6 months old) and that the symptoms of the needle-cast do not appear until the needles are about 1 year old.

The work described here supports and helps to explain the observation that although *C. minus* is common in the litter layer of *P. radiata* in New Zealand, the needle-cast caused by it is severe only in years with mild wet winters (Gilmour 1966). The weather in spring and summer when the current foliage is resistant to infection and the spore numbers are generally low cannot affect the incidence of the needle-cast. In autumn or winter, when the needles are susceptible to infection, wet periods of about 5 hours duration and temperatures above 10°C would provide good conditions for infection. Severe needle-cast in the spring would be expected after an autumn or winter in which such conditions prevailed.

3. VARIABILITY IN THE FUNGAL POPULATION

M. A. Dick, J. G. Somerville, and P. D. Gadgil

Abstract

Collections of *Pinus radiata* needles showing symptoms of Cyclaneusma needle-cast were made over two periods (1977 to 1983 and 1996 to 1998) throughout New Zealand. Differences in apothecium length and characteristics of *Cyclaneusma* grown on agar cultures indicated that there are at least two morphological types of *C. minus* in New Zealand; these are termed *C. minus* 'verum' and *C. minus* 'simile'. *Cyclaneusma minus* 'verum' was the most common type identified and *C. minus* 'simile' was found more often in the North Island (particularly the central North Island) than in the South Island.

3.1 SPECIES OF *CYCLANEUSMA*

Cyclaneusma minus was first recorded (as *Naemacyclus niveus*) in New Zealand on *Pinus radiata* and *P. ponderosa* (Gilmour 1959). The *Naemacyclus* on pines was subsequently separated into two species, *N. niveus* and *N. minor*, with *N. minor* the only species found on *P. radiata* (Butin 1973). In his evaluation, Butin examined the morphological characteristics of apothecia and ascospores on the needles, the formation of ascospores and pycnidiospores in culture, their morphology, and the relationship with different hosts. His data from the measurements made on *P. radiata* and *P. nigra,* are summarised in Table 3.1. He also found a generally consistent relationship between a host species and the species

of *Naemacyclus* which infected it. With the exception of *P. nigra* (95% *N. niveus* : 5% *N. minor*) and *P. montana* (96% *N. minor* : 4% *N. niveus*), only one species of *Naemacyclus* was found on each host examined. *Pinus ponderosa* and *P. mugo* were later listed as hosts for both species of *Naemacyclus* (Millar & Minter 1980; Minter & Millar 1980).

Species of *Naemacyclus* on pines were later assigned to a new genus, *Cyclaneusma,* as *C. minus* and *C. niveum* by DiCosmo *et al.* (1983). Both species of *Cyclaneusma* are present in New Zealand. The main characteristics distinguishing the two species are apothecium length (*C. niveum* apothecia are longer than those of *C. minus*) and pycnidiospore shape and length (bacilliform, 6.0– 9.5 mm in *C. minus*; sickle-shaped, 12–16 mm in *C. niveum*).

Morphological types of *C. minus* in New Zealand

In the course of the work on the biology of *Cyclaneusma* on *P. radiata*, it became apparent that although only one species, *C. minus*, was involved (as indicated by its bacilliform pycnidiospores), the apothecium size varied in different collections and the characteristics of fungal colonies in culture were consistently different enough to allow their separation into groups. At the beginning of the work, three or possibly four distinct cultural groups

TABLE 3.1 – Characteristics of *C. minus* and *C. niveum* (from Butin 1973).

	Cyclaneusma minus	*Cyclaneusma niveum*
In culture		
Mycelium	Growth uneven	Growth even, dense
Pycnidia	150–250 mm diameter	250–600 mm diameter
Pycnidiospores	6.5–8.0 mm long, bacilliform	9.0–15.5 mm long, sickle-shaped
Apothecia	Present	Absent
On needles		
Pycnidia	100–120 mm broad	120–220 mm broad
Pycnidiospores	6.0–9.5 mm long, bacilliform	12–16 mm long, sickle-shaped
Apothecia	190–580 × 140–240 mm	560–900 × 230–340 mm
Ascospores	81.8–92.5 × 2.5–3.0 mm, filiform, 2-septate	91.0–100 × 2.5–3.5 mm, filiform, 2-septate
Hosts	*Pinus caribaea, P. contorta, P. jeffreyi, P. montana, P. patula, P. ponderosa, P. radiata, P. strobus, P. sylvestris, (P. nigra)*	*P. halepensis, P. nigra, P. pinaster, (P. montana)*

could be distinguished but as the work progressed some characters were found to be not fully reliable and finally only two major groups could be maintained. One group showed all the attributes of *C. minus* as described by Butin (1973) and is referred to as *C. minus* 'verum'. The second group had cultural characteristics which tended towards *C. niveum* although it had bacilliform pycnidiospores and its apothecia were much shorter than those of *C. niveum*. This group is referred to as *C. minus* 'simile'. The cultural characteristics of the two groups are given in Table 3.2.

The extent of the variability in morphology was explored further in studies based on two separate series of collections made throughout New Zealand from 1977 to 1983 (Gadgil & Somerville) and from 1996 to 1998 (Dick).

3.2 METHODS

Collection of material, isolation procedures, and examination of cultures 1977–83

Collections of *P. radiata* needles infected with *C. minus* were made during the spring period of main symptom expression from throughout New Zealand from 1977 to 1983. Collections varied in composition and were made up either of green and yellowing needles picked from the trees or freshly cast needles or both. Some cast needles had developed apothecia and others had only the mottled yellow colouration typical of *Cyclaneusma* infection.

Isolations were made on 3% malt extract agar (MEA) from needles showing symptoms of *C. minus* infection, from green needles and directly from ascospores contained in the apothecia. Needles were cut into a standard 10 cm length and surface sterilised in 10 vols hydrogen peroxide, then rinsed in three changes of sterile distilled water before plating.

Four culture media (3% MEA, 7% MEA, 9% MEA, and Haegems agar) proved useful for promoting spore production. On malt extract agar at varying strengths, pycnidiospores and ascospores of *C. minus* 'verum' were formed after 21 days. Only two media were found on which *C. minus* 'simile' would form pycnidiospores; these were 9% MEA plus sterilised needles, and Haegems agar. Sporulation did not occur until 8 weeks after inoculation of the plates. Isolates obtained were examined at age 6 to 8 weeks and grouped into two cultural types based on morphology (Table 3.2).

Collection of material, isolation procedures, and examination of cultures 1996–98

Collections of *P. radiata* needles with symptoms of *C. minus* infection were made during the spring period of main symptom expression from throughout New Zealand from 1996 to 1998. Collections and isolations were made from 55 separate locations during the spring of 1996, 56 locations in 1997, and 116 locations in 1998. Collections consisted of green and yellowing needles from the trees and sometimes of needles collected from the litter. Thirty-two needles were randomly selected from each individual tree collection and an approximately 3-cm length from each of these needles (100 cm of needle length/ tree) was plated on to 3% MEA after surface sterilisation. Numbers of isolates developing in any one collection (100 cm of needle length) ranged from none to 38. The length of time between collection of a sample and plating often meant that other endophytic and saprophytic needle fungi out-competed the slower-growing *C. minus*. Colonies of *C. minus* were sub-cultured on to 3% MEA slants and petri dishes for preliminary examination.

Two basic cultural types which conformed to the broad descriptions of *C. minus* 'verum' and *C. minus* 'simile' provided by Gadgil & Somerville

TABLE 3.2 – Characteristics of *C. minus* 'verum' and *C. minus* 'simile' on 3% malt extract agar

	C. minus 'verum'	*C. minus* 'simile'
Mycelium	Mycelium pink-white, fluffy	Mycelium pink-beige, crusty
Colony margin	Margin diffuse and thin	Margin defined
Colony reverse	Reverse pink	Reverse brown
Sporulation	Ascospores and pycnidiospores formed	Only pycnidiospores formed
Pigmentation in agar	Brown pigmentation occasional	Dark-brown pigmentation of agar
Growth in tubes	Growth on lower slope of tube	Minimal growth on lower slope

(Table 3.2) could be readily distinguished (Fig. 3.1). Within these two groups each of the morphological characteristics listed formed a continuous gradient and it was not possible to separate subgroups with any confidence. The characteristics were markedly influenced by colony age and 20-day cultures compared with 40-or 60-day cultures of the same isolate could appear quite different.

Apothecium and ascospore measurements 1977–83

Needles from 45 collections were incubated for about 24 hours in damp chambers, and randomly selected apothecia were measured under a stereoscopic microscope. Ascospores were picked from the apothecia on needles from 10 collections under a stereo microscope, mounted in water, viewed under high magnification, and photomicrographs of random fields were taken. A micrometre scale was photographed at the same magnification and used for measuring ascospores appearing on the photomicrographs. Isolations were made individually from measured apothecia from seven collections.

Geographic distribution of *Cyclaneusma* types 1977–83 and 1996–98

The geographic distribution of the *C. minus* types was mapped. Data from only those collection sites which yielded six or more pure isolates were included. Collection sites were classified according to the biological regions defined by Crosby *et al.* (1976). A map showing these biological regions is given in Appendix 1.

3.3 RESULTS
Apothecium and ascospore measurements

The lengths of 5214 apothecia of *C. minus* on *P. radiata* needles from 45 collections were measured (Table 3.3).

The minimum apothecium length was 78 mm (collection from Pukeiti, Taranaki) and the maximum was 828 mm (Long Mile, Rotorua). Mean lengths in different collections ranged from 199 to 365 mm. Ascospore lengths (10 collections, 351 ascospores) ranged from 53 to 98 mm with the mean ranging from 65 to 80 mm.

There was considerable variation in the size of apothecia between and within collections and

FIG. 3.1 – Cultural forms of *C. minus* 'verum' (top) **and *C. minus* 'simile'** (bottom)

isolations from the collections yielded varying proportions of the two *C. minus* types. To explore the possibility that there was a direct relationship between apothecium size and *C. minus* type, apothecium lengths were measured and ascospores from each apothecium measured were picked and plated. Cultures of *C. minus* were obtained from 158 measured apothecia from seven collections. The

TABLE 3.3 – Mean ascospore and apothecium length of *Cyclaneusma* collections from *P. radiata* (1980)

Bioregion	Location	Age (years)	Ascospore length (µm)				Apothecium length (µm)			
			min.	mean	max.	(n)	min.	mean	max.	(n)
ND	Aupouri Forest	-	-	-	-	-	194	339	534	71
ND	Waitangi Forest, Cpt 22	10	-	-	-	-	155	295	476	100
ND	Puhipuhi Forest	-	-	-	-	-	175	292	427	69
ND	Puhipuhi Forest	-	-	-	-	-	223	356	466	28
ND	Poultons Block	-	-	-	-	-	136	270	447	92
WO	Tawarau Forest	7	-	-	-	-	97	200	349	73
WO	Ngaruawahia	7	-	-	-	-	107	226	398	91
BP	Long Mile, Rotorua	-	53	74	90	60	133	345	828	714
BP	Rotoehu Forest	6	57	67	98	37	117	279	485	90
BP	Athenree Forest, Cpt 14	9	66	80	96	26	155	252	485	102
GB	Patunamu Forest	-	-	-	-	-	116	212	369	150
TO	Kinleith Forest, Tram Rd	-	62	75	88	30	204	288	480	50
TO	Kinleith Forest, Rahui Rd	-	62	74	86	30	164	265	419	50
TO	Kinleith Forest, Rahui Rd	-	-	-	-	-	117	223	437	109
TO	Kinleith Forest Cashmores Blk	-	-	-	-	-	175	217	291	44
TO	Pureora Forest	6	-	-	-	-	126	257	466	71
TO	Kaingaroa Forest, Cpt 1022	-	53	65	78	50	82	227	501	570
TO	Tihoi	7	-	-	-	-	136	225	388	120
TO	Taupo	-	-	-	-	-	107	203	330	180
HB	Mohaka Forest Cpt 220	4	-	-	-	-	155	308	495	121
HB	Stoney Creek, Esk Forest	8	-	-	-	-	175	307	563	103
HB	Waikoau Blk	8	-	-	-	-	136	278	485	55
TO	Te Awahohonu Forest, Cpt 16	8	-	-	-	-	146	265	427	94
HB	Rukumoana Forest	9	-	-	-	-	116	262	456	114
HB	Crohane Forest	6	-	-	-	-	175	262	427	101
HB	Kaweka Forest, Cpt 32	8	-	-	-	-	155	247	408	101
WI	Waitarere	-	62	80	96	25	136	304	582	119
WI	Lake Wiritoa	15–16	-	-	-	-	155	296	505	128
WI	Bulls	8	-	-	-	-	175	288	621	80
WI	Manawatu	7	-	-	-	-	200	365	625	70
WI	Tangimoana Forest	51	-	-	-	-	194	340	563	120
WI	Lismore Forest, Cpt 66	10	-	-	-	-	146	231	515	90
WA	Eketahuna	5	62	75	90	30	175	313	621	112
WA	Makuri	2–4	62	72	94	36	194	310	582	75
WA	Pahiatua	3–4	-	-	-	-	194	305	485	59
WA	Ngaumu Forest, Cpt 301	4	66	75	92	27	136	271	437	85
WN	Shannon	6	-	-	-	-	175	293	466	84
WN	Pinehaven, Hutt Valley	5–6	-	-	-	-	116	252	563	82
WN	Akatarawa	8–9	-	-	-	-	155	216	369	97
MC	Eyrewell Forest, Cpt 63	-	-	-	-	-	175	316	466	65
TK	N.E. Hawera	10	-	-	-	-	175	335	660	123
TK	Te Wera Forest, Cpt 32	8	-	-	-	-	146	248	427	106
TK	Lake Mangamahoe	5–6	-	-	-	-	136	235	417	96
TK	Waitaanga, Justice Dept	4–5	-	-	-	-	136	225	388	80
TK	Pukeiti, N. Plymouth	8	-	-	-	-	78	199	388	80

- Data not available

cultures were assigned to type and it was found that apothecia < 290 mm in length generally yielded *C. minus* 'simile' and those > 290 mm generally yielded *C. minus* 'verum'. These results indicated that most collections consisted of a mixture of the two *C. minus* types.

Data from two collections (Long Mile at Rotorua, and Cpt 1022 Kaingaroa Forest) for which a large number of measurements of apothecium lengths were available were further separately analysed to test the hypothesis that the frequency distribution (of apothecium length) for each collection was a composite of two normal distributions. This analysis was carried out by Ian Andrew. For each set of data, five parameters (two means, two standard deviations, and one sample size) were estimated using an iterative Nelder-Mead simplex procedure (Nelder & Mead 1965) with the objective of minimising the log-likelihood ratio for the difference between the actual frequencies and those predicted by the composite normal distribution. The results are given in Table 3.4. The apothecium length frequencies for the two collections are shown in Fig 3.2. Two population distributions could be recognised in each collection; the Long Mile collection was principally *C. minus* 'verum' (86%) and the Kaingaroa collection was mainly *C. minus*

'simile' (76%). Isolation results from the collections yielded similar results, the Long Mile collection yielding 87% *C. minus* 'verum' and the Kaingaroa collection 89% *C. minus* 'simile'.

Geographic distribution of *Cyclaneusma* morphological types 1977–83

Cyclaneusma minus 'verum' was the most common type identified and was present in all samples apart from those taken at Kinleith Forest and Atiamuri. *Cyclaneusma minus* 'simile' was particularly common in Kaingaroa Forest. The two collections from Slopedown Forest showed variable results. One collection yielded only *C. minus* 'verum' while both types were found on the other collection. Sites of collections yielding large numbers of isolates, sometimes over several years, are listed in Table 3.5. The distribution of *C. minus* types is shown in Fig. 3.3.

TABLE 3.4 – Distributions of apothecium lengths from two populations within collections from Cpt 1022 Kaingaroa Forest, and Long Mile, Rotorua

Location	Population A (*C. minus* 'simile')			Population B (*C. minus* 'verum')		
	Mean (µm)	s.d.	Sample size	Mean (µm)	s.d.	Sample size
Cpt 1022, Kaingaroa Forest	194	34.5	423	277	42.3	133
Long Mile, Rotorua	237	33.4	97	368	98.3	600
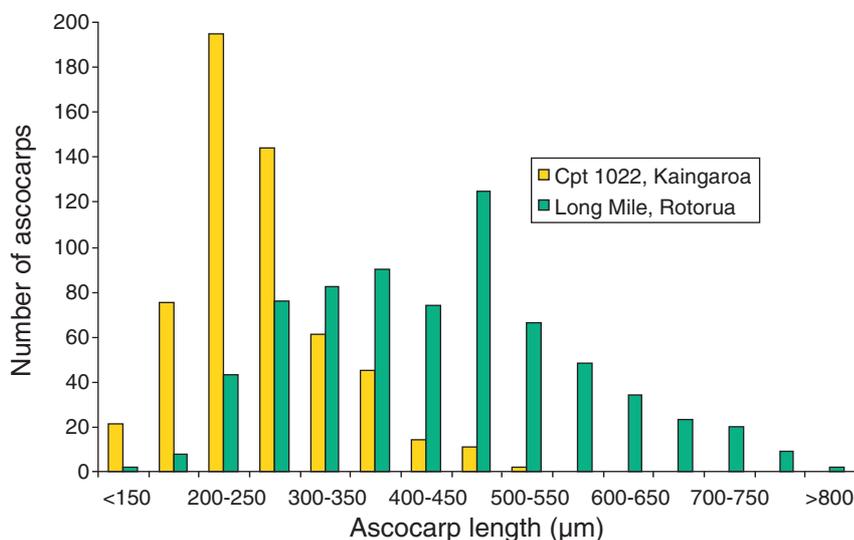
FIG. 3.2 – Frequency of occurrence of apothecium lengths. Collections from Long Mile, Rotorua, and Cpt 1022 Kaingaroa Forest

TABLE 3.5 – Location of collection sites

Location	Bioregion	Latitude	Longitude	Collection date
Aupouri Forest	Northland	35°00'	173°11'	Dec 1980
Long Mile, Rotorua	Bay of Plenty	38°09'	176°01'	1977–80
Atiamuri	Bay of Plenty	38°23'	176°01'	1981–83
Rahui Rd, Kinleith Forest	Taupo	38°16'	175°58'	Mar 1981
Cpt 1022, Kaingaroa Forest	Taupo	38°21'	176°26'	1977–79
Puruki Forest	Taupo	38°29'	176°16'	Nov 1981
Mangara Forest	Gisborne	38°03'	178°13'	Oct 1981
Ruatoria Forest	Gisborne	37°49'	178°02'	1981–83
Patunamu Forest	Gisborne	38°55'	177°13'	Nov 1981
Eketahuna	Wairarapa	40°39'	175°42'	Oct 1980
Pahiatua	Wairarapa	40°37'	175°50'	Dec 1980
Linton Army Camp, Manawatu	Wellington	40°25'	175°35'	Dec 1980
Kenepuru Forest	Marlborough Sounds	41°12'	173°58'	Nov 1981
Kaitangata Forest	Dunedin	46°18'	169°51'	Nov 1981
Slopedown Forest (a)	Southland	46°21'	169°06'	Nov 1981
Slopedown Forest (b)	Southland	46°17'	169°07'	Nov 1981
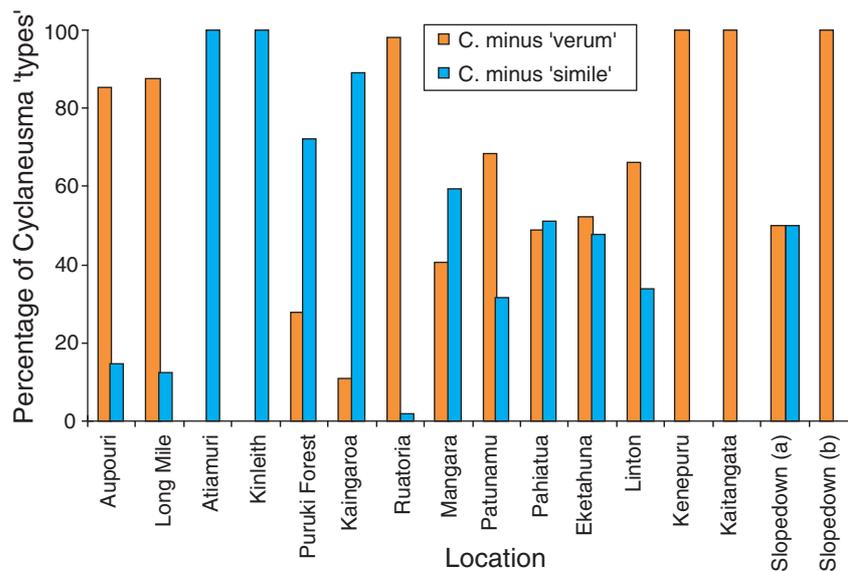
FIG. 3.3 – Percentage of *Cyclaneusma* types from various locations. Data collected from 1977 to 1983.

Geographic distribution of *Cyclaneusma* morphological types 1996–98

The small number of isolates obtained from some collections could not be considered truly representative of the population at such sites and these data were excluded from the evaluation. The locations of collection sites which yielded large numbers of isolates are given in Appendix 2. Repeat collections from individual forests often yielded quite different results. Data from Kinleith Forest and Onewhero Forest presented in Table 3.6 are representative of the trend (see also results from Slopedown Forest in Fig. 3.3), indicating that an

extremely large body of data would be necessary in order to be confident in assigning regional variation in distribution. Therefore, no direct comparisons can be made with the data collected by Gadgil & Somerville (shown in Fig. 3.3). The one trend consistent with that demonstrated by Gadgil & Somerville was that *C. minus* 'simile' was more common in the North Island and less common towards the south (Fig. 3.4). Collections over the 3-year period were made from trees ranging in age from 4 to 27 years, with the majority from trees aged 6 to 15 years. There was no correlation between tree age and *Cyclaneusma* type.

TABLE 3.6 – Percentage of *C. minus* 'verum' and *C. minus* 'simile' from Onewhero and Kinleith Forests.

Forest	Collection No.	Stand age	Season	*C. minus* 'verum'	*C. minus* 'simile'
Onewhero	Cpt 5	10	1997–98	66	33
	Cpt 5	10	1998–99	0	100
	Cpt 3	11	1998–99	0	100
	Cpt 1	12	1998–99	100	0
	Cpt 1	12	1998–99	100	0
Kinleith	Panda Rd	13	1996–97	100	0
	Hyena Rd	5	1996–97	0	100
	Wallace Rd	12	1998–99	0	100
	Ranui Rd	17	1998–99	0	100
	Tram Rd	5	1998–99	100	0
	Smythe Rd	14	1998–99	100	0
	Farm Rd	12	1998–99	15	85
	Puketutu Rd	7	1998–99	80	20
	Gem Rd	16	1998–99	25	75
	Smythe Rd	14	1998–99	0	100
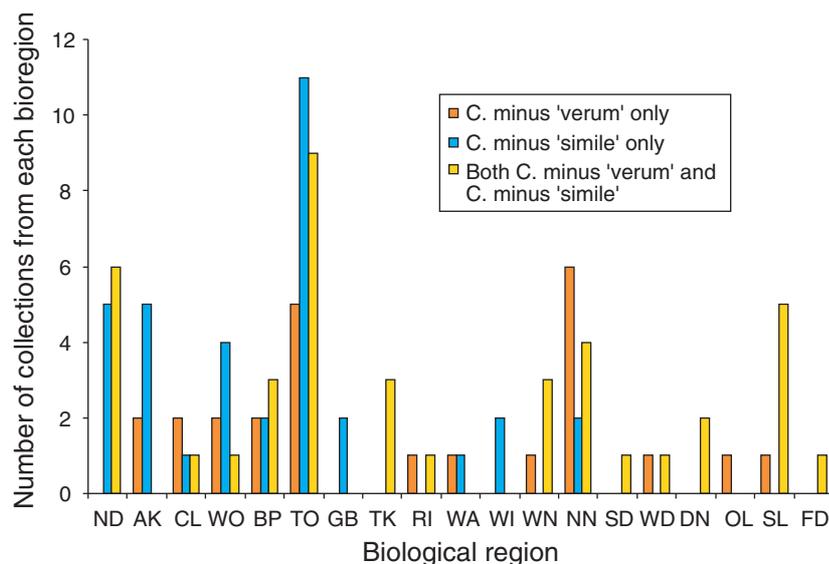
FIG. 3.4 – Geographical distribution of *Cyclaneusma* types. Data collected 1996–98.

3.4 DISCUSSION

Gadgil & Somerville, in their 1977–83 evaluation of *Cyclaneusma*, identified two morphological types in the New Zealand *C. minus* population. The cultures were distinguished on the basis of colony colour and texture, production of pigment, margin definition, and formation of fruiting structures. A relationship between apothecium dimensions from needles and colony morphology was demonstrated. Considerable variation existed within each type and a continuous gradient of characteristics prohibited the separation of further subgroups. The employment of other methods such as isozyme production and modern molecular techniques may demonstrate that further groupings exist.

Although at most sites examined during 1977–83 a mix of *C. minus* types could be found, there were instances where one (or predominantly one) type was consistently isolated. These results led to speculation that population structure may be an important factor contributing to regional variation in severity of needle-cast. However, within some forests, sites with similar disease levels which were sampled from 1996 to 1998 proved to have quite

different populations. There are a number of possible reasons for this variation. Host genotype is known to strongly influence symptom expression but further detail on the relationship between host and fungal genotype relationships needs to be gathered. Occasionally more than one type has been isolated from a single needle but this is relatively uncommon. Needles from trees belonging to a single clone of *P. radiata* from Long Mile, Rotorua, were colonised largely by one type (*C. minus* 'verum'). Many of the collections examined over the last 25 years have been of bulked needles from groups of trees and thus host/genotype relations have not been established. Equally, the reason for the variable results may be simply that an extremely large body of data is necessary in order to establish population levels and that insufficient data were collected in these studies.

Cyclaneusma minus is an early and extensive endophytic colonist of *P. radiata* needles (Gadgil 1984) and of other pine species (Rack & Scheidemann 1987; Sieber *et al.* 1999). Endophytism refers to the existence of one organism within the tissues of another with no immediate effect on host function or appearance.

Their further development may follow with either a saprophytic or overtly parasitic phase (Butin 1995). Fungal endophytism is extremely common in higher plants and results in associations which may be neutral, mutualistic, or latently antagonistic. *Cyclaneusma minus* can survive in green needles for periods of 2 months to 2 to 3 years before symptom expression (Kistler & Merrill 1978; Merrill, Kistler, Zang, & Bowen 1980; Gadgil 1984; Choi & Simpson 1991). In some other pine species no antagonistic relationship has been recorded (Helander *et al.* 1994; Sieber *et al.* 1999). This endophytic nature of *C. minus* has led to difficulties in interpreting of the role of the fungus in premature needle-cast. The presence of two, or possibly more, morphological types which may possibly vary in pathogenicity complicates the picture further.

A number of questions on the relationship between Cyclaneusma needle-cast, host genotype, and populations of *Cyclaneusma* in its various forms remain unanswered. Further examination of the relationship will be carried out with clonal selections of *P. radiata*, and pathogenicity tests on clonal *P. radiata* are planned for 2000–2001.

PART II:

DISTRIBUTION AND SIGNIFICANCE OF THE DISEASE

4. DISTRIBUTION OF CYCLANEUSMA NEEDLE-CAST IN NEW ZEALAND

L. S. Bulman

Abstract

Fifteen forests totalling 70 000 ha of *Pinus radiata* were surveyed for Cyclaneusma needle-cast in 1983, 1984, and 1985. Disease severity was highest in the 11- to 20-year-old stands and lowest in the 1- to 5-year-old and over 25-year-old stands. Disease severity generally increased from 1983 to 1984 to 1985 but there was significant variation between regions. The Northland, Gisborne, Bay of Plenty, and Taupo biological regions had the highest disease intensity, and Canterbury and Nelson had the least disease. Records from the Forest Health Database generally confirmed the findings of the aerial surveys. No difference in disease incidence between years could be demonstrated.

4.1 INTRODUCTION

Premature needle-cast caused by *Cyclaneusma minus* occurs widely in plantations of *P. radiata* throughout New Zealand. Years of severe needle-cast have been recorded since 1952 (Gadgil 1984). Van der Pas, Slater-Hayes, Gadgil, & Bulman (1984) showed that the same individual trees suffer heavy needle-cast year after year, but no detailed information was available on the annual variation of disease incidence and severity on a stand basis for consecutive seasons. Results were reported (van der Pas, Bulman, & Slater-Hayes 1984) from an aerial survey conducted throughout New Zealand in 1983. Follow-up surveys were completed in 1984 and 1985, and data from all three surveys are presented here. Records of Cyclaneusma needle-cast assessments were extracted from the Forest Health Database maintained by the New Zealand Forest Research Institute to provide additional data on severity of the disease in different regions.

4.2 METHODS

Forests sampled

Initial selection in 1983 aimed for a uniform geographical spread of forests throughout New Zealand, and a range of soil types and climate. Selection of forests for the 1984 and 1985 surveys was based on the forests surveyed in 1983.

However, six forests selected in 1983 — Woodhill, Karioi, Santoft, Balmoral, Herbert, and Ashley — were omitted in 1984 and 1985 because of difficulties experienced in distinguishing between the symptoms of other damage (salt spray, drought, snow damage) and those of Cyclaneusma needle-cast. Results of the Balmoral and Ashley 1983 assessments are given here to show data from the North Canterbury biological region (for area details, *see* van der Pas, Bulman, & Slater-Hayes 1984). Otago Coast Forest and Whakarewarewa Forest Park, not surveyed in 1983, were included in 1984 and 1985. Fifteen forests were surveyed in 1984 and 1985 (Table 4.1). Location, altitude, and mean rainfall data for April to June are given in Table 4.2.

Assessment

Disease severity was assessed using the 5% step method used for the assessment of Dothistroma needle blight (Kershaw *et al.* 1988). Disease

was assessed by estimating the percentage of trees in the stand that were infected by the disease (also using a 5% scale). From this estimate, the area occupied by infected trees in the stand was calculated. For all three surveys stands were scored by the same two assessors from a Cessna 180 aircraft flying at about 100 m above ground level at about 80 knots airspeed. "Disease incidence" is defined as the percentage of the stand area occupied by trees showing the yellowing foliage characteristic of Cyclaneusma needle-cast, while "Disease severity" is the average percentage of the tree crown with disease symptoms (van der Pas, Bulman, & Slater-Hayes 1984).

Analysis of data

Where data from all three surveys were to be analysed, disease incidence and severity data from 1983 were recalculated excluding the six forests omitted in 1984 and 1985 to eliminate bias when comparing 1983 results with the 1984 and 1985 results. The stands in each forest were classified into age groups: <5 years old, 6–10 years old, 11–

TABLE 4.1 – Area of *P. radiata* plantations (ha) surveyed for Cyclaneusma needle-cast

Forest	Year	Age-class (years)					Total
		1–5	6–10	11–20	21–25	>25	
Glenbervie	1983	66	693	572	78	21	1 430
	1984	172	629	1 136	83	109	2 129
	1985	0	204	1 548	245	80	2 077
Tairua	1983	190	674	1 391	48	163	2 466
	1984	108	839	1 614	99	106	2 766
	1985	60	430	1 695	207	48	2 440
Mangatu	1983	610	1 896	2 050	102	0	4 658
	1984	0	2 691	2 727	187	0	5 615
	1985	40	1 917	2 921	447	0	5 325
Ruatoria	1983	1286	4 260	608	0	0	6 154
	1984	419	4 907	1 550	0	0	6 876
	1985	111	4 123	2 555	0	0	6 789
Kaingaroa	1983	4044	8 079	8 560	1701	2532	24 916
	1984	2968	9 203	9 432	891	1172	23 666
	1985	1097	10 245	12 351	1590	1290	26 573
Whakarewarewa	1984	106	605	660	0	0	1 371
	1985	35	548	788	0	0	1 371
Pureora	1983	264	1 111	160	36	0	1 571
	1984	264	1 106	160	36	0	1 566
	1985	19	1 183	238	36	0	1 476
Patunamu	1983	208	801	319	88	121	1 537
	1984	16	674	443	167	35	1 335
	1985	0	663	524	85	61	1 333
Wharerata	1983	918	805	480	122	0	2 325
	1984	686	1 087	348	122	0	2 243
	1985	227	1 456	480	122	0	2 285
Mohaka	1983	150	924	800	38	0	1 912
	1984	0	1 012	1 436	134	0	2 582
	1985	0	903	1 418	175	0	2 496
Gwavas	1983	164	703	884	240	12	2 003
	1984	76	311	1 323	287	21	2 018
	1985	39	486	1 091	242	59	1 917
Golden Downs	1983	1021	3 906	5 417	415	178	10 937
	1984	735	2 739	6 542	629	218	10 863
	1985	196	2 535	7 464	906	111	11 212
Mawhera	1983	51	1 463	680	0	0	2 194
	1984	0	1 006	982	0	0	1 998
	1985	0	944	1 160	75	0	2 179
Otago Coast	1984	81	1 921	2 669	304	0	4 975
	1985	81	1 367	3 216	401	0	5 065
Berwick	1983	647	3 115	2 046	239	0	6 047
	1984	0	67	1 794	160	0	2 021
	1985	0	0	1 590	274	0	1 864
Total	1983	9619	28 430	23 967	3107	3027	68 150
	1984	5631	28 797	32 826	3099	1661	72 014
	1985	1905	27 004	39 039	4805	1649	74 402
Area* (%)	1983	19.3	54.0	47.6	32.7	15.1	37.4
	1984	11.4	50.4	52.7	26.2	8.9	36.2
	1985	4.0	48.7	55.8	33.4	9.0	36.2

* Area (%) is the percentage surveyed of the total area (total area was obtained from the Stand Record System, *see* Table 4.7) in each age-class for the 15 forests.

TABLE 4.2 – Geographic particulars of the surveyed forests

Forest	Biological region	Latitude (S)	Longitude (E)	Altitude (m)	Rainfall* April-June (mm)
Glenbervie	Northland	35°39'	174°21'	100–200	562
Tairua	Coromandel	37°10'	175°51'	1–250	554
Ruatoria	Gisborne	37°51'	178°05'	60–300	861
Whakarewarewa	Bay of Plenty	38°10'	176°16'	300–450	417
Mangatu	Gisborne	38°17'	177°51'	170–280	381
Kaingaroa	Bay of Plenty/Taupo	38°24'	176°34'	540–760	409
Pureora	Taupo	38°31'	175°53'	550–600	498
Patunamu	Gisborne	38°56'	177°14'	100–160	381
Wharerata	Gisborne	38°55'	177°48'	50–350	767
Mohaka	Hawke's Bay	39°04'	177°02'	220–340	413
Gwavas	Rangitikei	39°44'	176°27'	320–420	310
Golden Downs	Nelson	41°33'	172°53'	270–340	358
Mawhera	Buller	42°47'	171°30'	220–350	754
Balmoral	North Canterbury	42°49'	172°45'	190–220	173
Ashley	North Canterbury	43°11'	172°35'	100–400	211
Berwick	Dunedin	45°55'	169°58'	20–450	189
Otago Coast	Dunedin	46°05'	170°06'	50–240	212

* New Zealand Meteorological Service (1979)

20 years old, 21–25 years old, and >25 years old. Sample size in each age-class was estimated as approximately proportional to disease intensity, based on data from the 1983 survey. This initial survey indicated disease severity was low in the 1- to 5-year-old and >25-year-old stands, and so approximately 10% of these age-classes and 50% of the 6- to 20-year-old stands in each forest were randomly selected for assessment. This stratified random sampling technique, with proportional allocation, increased efficiency without a loss of accuracy and precision — an important factor because flying costs were high. The percentage of the total area sampled in the 1- to 5-year-old age-class decreased each year owing to shifts in the age-class distribution for the successive surveys.

Data from both assessors were averaged to provide one assessment figure for each compartment surveyed. The data were grouped into the five age-classes. For each age-class, compartments were ranked according to disease severity in 10% steps, i.e., trace (disease present but less than 1%), 1–10%, 11–20%, 21–30%, etc. The disease incidence data were used to calculate the total area infected for each severity rank. For instance, if a compartment had a net stocked area of 100 ha and a rating of 20% incidence and 25% severity, a total of 20 ha would be added to the 21–30% severity rank. Total net stocked area for each rank was obtained from the Stand Record System (Shirley 1983). The total area occupied by diseased trees was related to the total net stocked area, by age-class, to give the average infection rating for each severity rank.

Individual observer assessments for the 1984 and 1985 surveys were compared using the paired comparison t-test. Differences among disease severity and incidence for the 15 forests by year were tested by analysis of variance.

4.3 RESULTS

Effect of tree age

Disease incidence and severity data by age-class are given for individual forests in Table 4.3 and summarised by age-classes in Table 4.4. Disease severity was low in the 1- to 5-years and >25-years age-classes, apart from one 5-year-old stand at Ruatoria with 61–70% severity in 1984, and two >25-years stands at Glenbervie with 51–60% and 71–80% severity in 1985. Disease severity was highest in the 6–10 years and 11–20 years age-classes with over 40% infection severity in 1% and 3% (1983), 6% and 10% (1984), and 7% and 11% (1985), respectively, of the stands sampled. Disease incidence was highest in the >25-year age-class with 82%, 86% and 81% of the stands being infected in 1983, 1984 and 1985; however, 79%,

84% and 77% of the areas surveyed had only a trace of the disease. Disease incidence in the severity rankings between 41% and 90% increased from 1983 to 1984 and 1984 to 1985 in the age-classes 6–10, 11–20, 21–25, and >25 years by 5% and 4%, 2% and 6%, 3% and 2%, and 0% and 2% respectively.

Effect of forest location

The disease was present throughout New Zealand, but with a considerable variation in disease incidence according to location (Table 4.5). In 1983, disease severity was highest in the central North Island and East Cape. In 1984 the forests surveyed

TABLE 4.3 – Disease incidence (%) for individual forests for 6- to 20-year-old trees

Forest	Year	Disease severity (%)								
		1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90
Glenbervie	1983	1	4	3	6	-	-	-	-	-
	1984	-	1	3	3	1	1	-	-	-
	1985	-	-	1	2	4	3	9	6	1
Tairua	1983	8	3	1	-	-	-	-	-	-
	1984	1	1	2	4	3	3	-	-	-
	1985	1	1	2	4	5	2	-	-	-
Mangatu	1983	4	7	1	4	5	2	-	-	-
	1984	1	1	7		2	4	6	-	-
	1985	-	-	3	2	3	7	10	1	-
Ruatoria	1983	2	6	4	10	2	-	-	-	-
	1984	-	1	1	2	3	2	14	8	-
	1985	-	1	1	3	3	9	7	4	-
Kaingaroa	1983	8	9	4	3	2	1	-	-	-
	1984	3	4	7	8	3	1	-	-	-
	1985	2	2	2	5	7	4	1	-	-
Whakarewarewa	1984	-	-	1	14	7	4	-	-	-
	1985	-	-	2	4	7	8	3	-	-
Pureora	1983	1	-	12	6	-	-	-	-	-
	1984	2	7	14	10	-	-	-	-	-
	1985	-	-	-	1	8	18	6	-	-
Patunamu	1983	7	2	2	-	-	-	-	-	-
	1984	4	4	-	4	1	-	-	-	-
	1985	6	1	-	1	-	-	-	-	-
Wharerata	1983	8	3	6	-	-	-	-	-	-
	1984	1	11	4	2	-	-	-	-	-
	1985	2	4	-	3	1	4	-	3	3
Mohaka	1983	8	2	-	-	-	-	-	-	-
	1984	2	5	4	2	1	-	-	-	-
	1985	5	3	1	2	1	-	-	-	-
Gwavas	1983	4	11	3	1	-	-	-	-	-
	1984	3	4	4	3	1	-	-	-	-
	1985	3	1	1	3	4	-	-	-	-
Golden Downs	1983	9	7	1	-	-	-	-	-	-
	1984	6	3	1	-	-	-	-	-	-
	1985	6	3	1	-	-	-	-	-	-
Mawhera	1983	9	11	4	2	-	-	-	-	-
	1984	7	8	1	-	-	-	-	-	-
	1985	3	7	2	-	-	-	-	-	-
Balmoral	1983	8	-	-	-	-	-	-	-	-
Ashley	1983	10	-	-	-	-	-	-	-	-
Otago Coast	1984	1	2	2	2	2	4	3	1	-
	1985	5	3	1	1	-	-	-	-	-
Berwick	1983	10	3	9	5	-	-	-	-	-
	1984	1	6	9	7	-	1	2	1	-
	1985	6	4	3	-	-	-	-	-	-

in the East Cape and Otago regions were most severely infected, with l5% (East Cape) and 8% (Otago) of those areas having severity ratings over 40%. In 1985 Northland, the central North Island, and East Cape had the highest disease intensity with severity ratings over 40% in 23%, 11%, and 20% of the areas surveyed respectively. Disease severity was low (not greater than 40%) in Westland and

TABLE 4.4 – Disease incidence (expressed as percentage of the area surveyed occupied by diseased trees) for severity rankings by age-class

Age (years)	Year	Disease severity (%)					Total incidence (%)
		Trace	1–20	21–40	41–60	>60	
1–5	1983	20	9	-	-	-	29
	1984	22	7	2	-	1	32
	1985	1	10	-	-	-	11
6–10	1983	1	14	6	1	-	22
	1984	1	7	9	3	3	23
	1985	-	5	5	7	3	20
11–20	1983	1	13	9	3	-	26
	1984	3	5	7	4	1	20
	1985	-	4	4	7	4	19
21–25	1983	3	16	3	-	-	22
	1984	10	6	2	2	1	21
	1985	3	7	2	3	2	17
>25	1983	79	3	-	-	-	82
	1984	84	2	-	-	-	86
	1985	77	2	-	1	1	81

TABLE 4.5 – Disease incidence for severity rankings by region

Region	Year	Disease severity (%)				Total incidence (%)
		1–20	21–40	41–60	>60	
Northland	1983	5	9	-	-	14
	1984	1	6	2	-	9
	1985	-	3	7	16	26
Coromandel	1983	11	1	-	-	12
	1984	2	6	6	-	14
	1985	1	6	7	-	14
Central North Island	1983	13	5	2	-	20
	1984	6	13	4	-	23
	1985	3	7	10	1	21
East Cape	1983	9	7	3	-	19
	1984	3	4	4	11	22
	1985	3	5	10	10	28
Hawke's Bay	1983	12	2	-	-	14
	1984	7	6	1	-	14
	1985	6	3	2	-	11
Nelson	1983	16	1	-	-	17
	1984	9	1	-	-	10
	1985	9	1	-	-	10
Westland	1983	20	6	-	-	26
	1984	15	1	-	-	16
	1985	10	2	-	-	12
Canterbury	1983	9	-	-	-	9
Otago	1983	13	13	-	-	26
	1984	4	8	5	3	20
	1985	8	2	-	-	10

Nelson in all 3 years and was high in Otago in 1984 only.

Mean disease severity for the 15 forests increased from 16% in 1983 to 31% in 1984 and 33% in 1985. Disease incidence remained constant at 18% in 1983 and 17% in 1984 and 1985. Differences in disease severity by survey year were significant at the 1% level. The degree of variation between assessors was low. Of the four variables tested (disease incidence and severity, in 1984 and in 1985) mean differences between assessors were not more than 3%.

Forest health inspection data

The Forest Health Database contains approximately 100,000 records, the great majority of which are derived from forest health inspections carried out since 1971. The primary purpose of carrying out forest health inspections is the detection of newly-introduced pests and diseases rather than the assessment of current stand health conditions, and so in some cases the data are limited by the intensity of survey prescribed for particular regions. However, data collected over 30 years of forest health inspections provide an indication of the regional intensity of specific pests or diseases. In Table 4.6 the number of records of Cyclaneusma needle-cast noted as a disorder during forest health inspections is shown. Only inspections carried out during the September to December period (the peak period of needle-cast) were considered in the analysis to ensure that a record of low severity was genuine and not a result of the inspection being carried out at a time of year when disease expression was low. Severity was assessed as high, medium, or low but in some instances the severity assessment was not recorded. Northland, East Cape, central North Island, Westland, and Otago had the highest incidence of high severity and Central Otago, Canterbury, and lower North Island were regions where severity was most commonly assessed as low.

Effect of microsite

The aerial survey data and records from the forest health database show that Northland, East Cape, central North Island, and Otago are regions of highest *Cyclaneusma* risk. This is probably because the climate in these regions is favourable for *Cyclaneusma*. Gadgil (1984) demonstrated that

temperatures over 10°C in autumn/winter and rainfall of over 5 hours' duration are optimal conditions for infection. Cyclaneusma needle-cast should not be a problem in regions where autumn-winter rainfall is low.

However, disease severity is variable within regions. Some microsites are more favourable to disease — for instance, ridge tops and high altitude sites. The phenomenon of increasing disease with increasing altitude has been recorded at Mamaranui, Ruatoria, and Wellington in the trial described in Chapter 5, and in five permanent sample plots assessed at Mamaranui (Table 4.7). The data shown for Mamaranui, Ruatoria, and Wellington are average disease severity ratings for all trees in each plot (those selected as healthy and those selected as diseased). Differences in disease incidence and severity at different altitudes are therefore masked because of the deliberate selection of diseased trees. Despite this, it is apparent that the plots at lower altitudes had less disease, particularly at Ruatoria. In the same general location of the disease/growth assessment plots at Mamaranui, four PSPs were located and these were assessed for Cyclaneusma needle-cast when the other plots were visited. Another PSP (Plot 5) was located approximately 2 km on the coastal side of the other plots. The PSPs had 50–60 trees per plot, apart from Plot 5 where over 900 trees were assessed. These assessments provide a better indication of disease severity because all trees within a circular 0.1 ha area (approximately 3 ha for Plot 5) were assessed. Plot 3 had significantly higher disease than the other plots, and heavily diseased trees were extremely rare in Plot 5, even though it was only 2 km from the other plots.

The relationship between altitude and disease severity was also observed during the aerial surveys (unpublished Forest Health Observers' notes, available from L. S. Bulman) of the mid-1980s at Glenbervie, Mangatu, Wharerata, and Otago Coast. The author has also observed this from the ground at several forests in Northland and Auckland, Mangatu, and Te Awahohonu in the central North Island.

TABLE 4.6 – *Cyclaneusma* **disorder records (assessed as high, medium, or low severity; or unspecified) extracted from the Forest Health Database for the months September to December from 1971 to 1999.**

Biological region	Number of records					Percentage of total			
	–	High	Medium	Low	Total	–	High	Medium	Low
Auckland	1	10	1	8	20	5.0	50.0	5.0	40.0
Northland	1	8	6	3	18	5.6	44.4	33.3	16.7
	2	**18**	**7**	**11**	**38**	**5.3**	**47.2**	**19.2**	**28.3**
Coromandel	1	1	7	2	11	9.1	9.1	63.6	18.2
	1	**1**	**7**	**2**	**11**	**9.1**	**9.1**	**63.6**	**18.2**
Waikato	6	43	48	29	126	4.8	34.1	38.1	23.0
Taranaki	7	8	15	20	50	14.0	16.0	30.0	40.0
Bay of Plenty	30	100	222	112	464	6.5	21.6	47.8	24.1
Taupo	58	150	294	151	653	8.9	23.0	45.0	23.1
	101	**301**	**579**	**312**	**1293**	**8.5**	**23.7**	**40.2**	**27.6**
Gisborne	16	14	12	10	52	30.8	26.9	23.1	19.2
	16	**14**	**12**	**10**	**52**	**30.8**	**26.9**	**23.1**	**19.2**
Hawke's Bay	17	6	17	41	81	21.0	7.4	21.0	50.6
Rangitikei	3	3	14	14	34	8.8	8.8	41.2	41.2
Wanganui	11	7	9	34	61	18.0	11.5	14.8	55.7
	31	**16**	**40**	**89**	**176**	**15.9**	**9.2**	**25.6**	**49.2**
Wellington	9	15	27	30	81	11.1	18.5	33.3	37.0
Wairarapa	3	1	12	12	28	10.7	3.6	42.9	42.9
	12	**16**	**39**	**42**	**109**	**10.9**	**11.0**	**38.1**	**39.9**
Marlborough Sounds	0	0	2	1	3	0.0	0.0	66.7	33.3
Marlborough	1	2	3	1	7	14.3	28.6	42.9	14.3
Nelson	11	39	95	42	187	5.9	20.9	50.8	22.5
	12	**41**	**100**	**44**	**197**	**6.7**	**16.5**	**53.4**	**23.4**
Buller	2	2	6	13	23	8.7	8.7	26.1	56.5
Westland	1	2	0	2	5	20.0	40.0	0.0	40.0
Fiordland	0	4	1	4	9	0.0	44.4	11.1	44.4
	3	**8**	**7**	**19**	**37**	**9.6**	**31.0**	**12.4**	**47.0**
Mid Canterbury	13	2	1	15	31	41.9	6.5	3.2	48.4
North Canterbury	5	0	2	10	17	29.4	0.0	11.8	58.8
South Canterbury	5	1	2	8	16	31.3	6.3	12.5	50.0
	23	**3**	**5**	**33**	**64**	**34.2**	**4.2**	**9.2**	**52.4**
Central Otago	2	0	3	5	10	20.0	0.0	30.0	50.0
Otago Lakes	0	0	0	4	4	0.0	0.0	0.0	100.0
	2	**0**	**3**	**9**	**14**	**10.0**	**0.0**	**15.0**	**75.0**
Dunedin	9	41	39	39	128	7.0	32.0	30.5	30.5
Southland	2	15	13	20	50	4.0	30.0	26.0	40.0
	11	**56**	**52**	**59**	**178**	**5.5**	**31.0**	**28.2**	**35.2**

– severity not specified

TABLE 4.7 – Cyclaneusma needle-cast assessments

Location	Plot number	Altitude (m)	Average disease severity (%)
Mamaranui	3	380	58
	1	300	69
	5	300	57
	2	240	60
	4	200	48
Mamaranui PSP	3	400	35
	1	300	20
	2	290	19
	4	190	17
	5	50	<5
Ruatoria	1	550	62
	2	520	49
	3	500	41
	4	330	37
		200	15
Wellington	1	300	70
	2	280	64
	3	200	61
	4	180	52
	5	160	42

4.4 DISCUSSION

Cyclaneusma needle-cast was most severe in stands aged 11–20 years. This confirms the findings of van der Pas, Bulman, & Slater-Hayes (1984). Disease severity increased from 1983 to 1984, and again in 1985, but there was no significant difference in disease incidence by survey year. Van der Pas, Slater-Hayes, Gadgil, & Bulman (1984) found annual severity levels of healthy and infected trees were highly correlated for up to 4 years' duration. This suggests that the proportion of trees affected by the disease within a given stand remains relatively constant from year to year, but the degree of infection of those susceptible trees may change significantly with time.

It is expected that stands within the age-classes 11–20 years, and to a lesser extent 6–10 years, will be most severely infected from year to year. Disease incidence was highest in the >25-year age-class, but was of little significance because disease severity in these stands was consistently low.

These data show that Cyclaneusma needle-cast is a damaging disease in some pine plantations. The East Cape forests were severely infected for three consecutive seasons, and severe outbreaks were recorded in Otago, Northland, and the central North Island. Data from the Forest Health Database generally confirmed these findings, with the exception of Westland. The one forest in Westland which was assessed during the aerial survey had low disease severity but 31% of the database records of the disease in Westland note the disease severity as high. This demonstrates the need to take care when interpreting regional severity ratings. Some forests within a particular region, or sites within a forest, may be subject to climatic conditions different from those generally prevalent in the region and therefore may show disease severities that differ from the regional norm. For instance, in Wellington, disease is severe in the stand selected for the disease/growth loss trial, particularly at higher altitudes (*see* Table 4.7). A neighbouring north-facing stand has little disease, and, generally, Cyclaneusma needle-cast is not particularly damaging in the Wellington region. Conversely, the disease may not be a problem on some sites within a high-risk region.

At higher altitudes mist and low cloud are more prevalent. The effect of mist is interesting, as the duration of needle surface wetness does not affect the infection process. The great majority of Ascomycetes, the fungal group to which *Cyclaneusma* belongs, require hydration of their fruiting structures for ascospore release to occur (Ingold 1971). Pawsey (1967) found peak spore

concentrations occurred within 2–3 hours of the onset of rain, and Gadgil (1984) found that the maximum effect of rain on spore release occurred in the fifth hour after the commencement of rainfall. It may well be that the mist and low cloud at higher altitude acts as a surrogate for rainfall after short, light showers, thereby maintaining hydration of apothecia which allows maximum spore release to occur. At lower altitudes, a short period of rain may not be sufficient to penetrate the canopy and wet the litter fully, and the litter would dry out faster in the less humid conditions prevailing. Therefore, it is probable that trees growing in areas where mist and low cloud are common are subjected to higher, and more frequent, inoculum loads. This effect is not confined to high areas, but also occurs in gully situations at some sites (unpublished data available from L. S. Bulman).

5. EFFECT OF CYCLANEUSMA NEEDLE-CAST ON GROWTH

L. S. Bulman and J. B. van der Pas

(a) Volume Growth

Abstract

Twenty pairs of 9-year-old final-crop trees were selected in a stand of *Pinus radiata* heavily infected with *Cyclaneusma minus* at Kaingaroa Forest in 1977. Each pair consisted of one heavily diseased tree and one healthy tree. Disease severity, in terms of percentage of crown infected, was recorded annually. Relationships between disease severity and growth were studied by complete stem analysis at tree age 15 years. Annual volume increments of the diseased trees were significantly reduced from age 7 onwards. Reduced diameter growth in the lower parts of the stem of the diseased trees caused small changes in the relative diameter distribution. The relationship between disease severity and volume loss showed a reduction of the average volume increment of approximately 60% at an average disease severity of 80%.

5.1 INTRODUCTION

This section describes a trial set up to elucidate the relationship between growth loss and disease severity in a stand of *P. radiata* infected by *C. minus* in Kaingaroa Forest.

5.2 METHODS

Site

In 1977, an area of approximately 0.5 ha was selected in the centre of a stand (65 ha) of 9-year-old *P. radiata* in Kaingaroa Forest. The stand was on a level site that was aerially seeded in 1968. The initial stocking of 4200 stems/ha had been thinned in 1971, 1974, and 1977 to respectively 2604 stems/ha, 1144 stems/ha, and 400 final-crop stems/ha. Dothistroma needle-blight was not present in the stand and it had not been sprayed with fungicide at any time. Field observations indicated that approximately 50% of the trees in the stand showed symptoms of Cyclaneusma needle-cast, although the severity of infection varied. The affected trees were scattered among others that showed no visible symptoms of ill health and had normal green crowns.

The study was carried out over 6 consecutive years. In 1977, after the last thinning, 40 of the final-crop trees were selected in pairs. Each pair consisted of a healthy and a heavily diseased tree of approximately equal diameter at breast height (dbh), crown height, and crown width at time of selection. Paired trees, representing the full range of tree sizes, were randomly selected. The healthy trees were free from any visible infection whereas the diseased trees showed premature needle-cast of more than 65% of the crown. Volume loss due to defoliation caused by the fungus was measured at age 15 by comparing annual growth of the healthy and diseased trees.

Treatments

In March 1980, nine randomly selected pairs of healthy and diseased trees were injected with a carbendazim solution. This fungicide has been shown to control Cyclaneusma needle-cast (Hood & Vanner 1984). The solution consisted of 3.5 g methyl benzimidazol-2-yl carbamate dissolved in 8.75 ml concentrated hydrochloric acid made up to 1 litre with water. The doses applied were 4 litres for trees with a dbh of less than 18 cm, 5 litres for those from 18 to 25 cm dbh, and 6 litres for those larger than 25 cm dbh. The solution was gravity fed through five equidistant holes (1.2 cm diameter, 3 cm deep) drilled through the bark 30 cm above ground level. The uptake of the solution took place within 5 days for all trees. A second dose was applied to the same trees in November 1981. Dose volumes were increased depending on the size of the tree and ranged from 4 to 17 litres/tree. The uptake this time was slow and some trees took much less than the applied volume.

Disease scoring

Disease severity was visually estimated for each tree using a method similar to that used for the assessment of Dothistroma needle-blight (Kershaw *et al.* 1988). The percentage of the normal green

crown that showed visible symptoms of infection by *C. minus* was estimated in 5% steps by three trained observers whose individual scores were averaged. Scoring was carried out weekly over a 6-week period in September and October each year, the period when maximum symptom expression could be identified for each individual tree. Foliage samples were taken from each tree and isolations made of the fungi present inside the needle tissues in June and November 1977 and 1978, May and November 1979, and September 1980 using methods outlined previously (Chapter 2).

Analyses

In July 1983, all sample trees were felled for a complete stem analysis of past growth. After felling, sections were cut at mid-internodes and diameters were measured within each annual shoot (Whyte 1974). Cumulative volumes and annual volume increments were calculated, and growth increments were plotted using program package GRANRAD (unpublished data, available from L.S.Bulman on request). Growth increments were tested by analysis of covariance with height and volume of previous years used as covariates.

5.3 RESULTS AND DISCUSSION

The average annual disease severity of the diseased trees was significantly higher than that of the healthy trees (p < 0.01) from 1977 to 1982 (Table 5.1). Some of the initially healthy trees became diseased in 1978 but the disease severity for these trees remained low.

Injection with carbendazim reduced the disease severity of both the diseased trees and healthy trees with light infection. This agrees with Hood & Vanner (1984) who found that stem injections of

carbendazim gave significant control of Cyclaneusma needle-cast in a single susceptible clone of *P. radiata*. In this trial, however, improvement in crown health after carbendazim injection was not as marked and contrasts between injected and control trees could not be clearly distinguished statistically. The reason may lie in chance irregularities caused by the small sample size. The reduced level of control may have been due also to the much reduced uptake of solution by some trees during the second application.

The annual disease severity levels were highly correlated (r = 0.65 to 0.91 between severity levels up to 4 years apart). This suggests that susceptibility of individual trees to the disease remained relatively constant during the period of investigation, although there was annual variation in disease severity among the susceptible trees. Isolations made from the foliage samples showed that the populations of *C. minus* were significantly higher in the needles of the diseased trees than in those of healthy trees (Table 5.2). Injection with carbendazim also reduced population levels. There was no difference between the populations of *Lophodermium* spp., which usually follow *C. minus* by about 1 month in the needle colonisation sequence (Gadgil 1984).

Growth loss

Height growth was not significantly reduced by the disease (Table 5.3) and the average total height of the diseased trees (20.4 m) was only slightly less than that of the healthy trees (21.7 m) at age 15. This agrees with other findings that height growth is not significantly affected by artificial partial defoliation (Rook & Whyte 1976) or by defoliation by leaf pathogens such as *Dothistroma pini* (Whyte 1976; van der Pas 1981).

TABLE 5.1 – Average annual disease severity of healthy and diseased trees (percentage of green crown infected)

Category	Year						Average
	1977	1978	1979	1980	1981	1982	1977–82
Healthy/not injected	0	20	12	21	20	23	16
Healthy/injected	0	0	0	13	0	0	2
Average	0	10	6	17	10	11	9
Diseased/not injected	74	72	64	70	67	58	67
Diseased/injected	77	64	48	47	37	29	50
Average	75	68	56	58	52	44	59

TABLE 5.2 – Number of isolates of *C. minus* and *Lophodermium* spp. per 10 cm of needle length

Date	*Cyclaneusma minus*		*Lophodermium* spp.	
	Healthy trees	Diseased trees	Healthy trees	Diseased trees
1977 June	2.7	3.2	1.3	2.5
1977 November	0.5	3.0	2.7	4.5
1978 June	2.0	3.2	0.5	1.7
1978 November	1.8	7.0	13.0	27.0
1979 May	0.3	1.3	1.3	6.5
1979 November	1.0	3.5	4.3	4.5
1980 September (non inj.)	12.2	25.2	0.5	9.4
1980 September (inj.)	8.3	10.6	7.5	9.4

TABLE 5.3 – Average annual volume and height increments of healthy and diseased trees from 1969 to 1983

Season	Healthy trees				Diseased trees			
	Height increment (m)	Volume increment (dm^3)			Height increment (m)	Volume increment (dm^3)		
		Control	Injected	Pooled		Control	Injected	Pooled
1968/69	0.5	0.05	0.04	0.04	0.5	0.10	0.06	0.08
1969/70	1.0	0.22	0.24	0.25	1.0	0.53	0.33	0.44
1970/71	1.1	1.1	1.0	1.0	1.2	1.8	2.2	2.2
1971/72	1.3	4.1	3.8	3.9	1.5	5.1	4.8	5.0
1972/73	1.7	8.2	7.9	7.9	1.7	11.9	9.7	10.8
1973/74	1.7	16.3	14.3	15.1	1.6	19.3	16.5	17.9
1974/75	1.7	29	26	27a	1.7	28	24	26
1975/76	1.7	27	27	26a	1.5	28	23	25
1976/77	1.7	39	35	36a	1.6	31	28	30
1977/78	1.7	58	62	58a	1.5	35	34	35
1978/79	1.6	76	83	77a	1.6	51	53	52
1979/80	1.6	100	112	103a	1.5	59	59	59
1980/81	1.7	121	142b	128a	1.4	67	82b	74
1981/82	1.3	116	140b	125a	1.3	59	81b	69
1982/83	1.6	123	151b	133a	1.4	70	91b	79

a   Volume increment of healthy trees significantly higher than of control trees ($p<0.01$)
b   Volume increment of injected trees significantly higher than of control trees ($p<0.01$)

Annual volume growth of the trees selected as diseased was slightly faster than that of the healthy trees during the first years after establishment from 1970 to 1974 (Fig. 5.1). Volume growth of both categories was approximately similar in 1975 and 1976. From 1977 onwards, annual volume increments of the diseased trees were increasingly reduced. Analysis of covariance (for adjusted values, *see* van der Pas, Slater-Hayes, Gadgil, & Bulman 1984) indicated that growth differences between healthy and diseased trees were not significant from 1970 to 1974. Growth reduction of the diseased trees was significant from 1975 onwards. This suggests that severe needle-cast started as early as age 7, which agrees with field observations about the onset of the disease. By 1983, average volume of the healthy trees was 742 dm^3 compared with 488 dm^3 for the diseased trees.

Injection with the fungicide solution resulted in significantly faster growth in healthy and diseased trees than in the controls ($p <0.01$) from the 1980/81 to 1982/83 growth seasons (Table 5.3). The response in the healthy trees suggests that carbendazim may supplement the nitrogen requirements of the trees. The active ingredient consists of 22% by weight of nitrogen (Hood & van der Pas 1979) and it is estimated that the injected trees received a total of between 9 and 12 g nitrogen each (average 10 g; approximately equivalent to 2 kg N/ha/year, over 2 years). Although this is not a great quantity when compared with fertiliser applications, it is still a contribution that may account for some of the growth response.

The growth sequences of the diseased trees suggest that growth reduction due to *Cyclaneusma* may
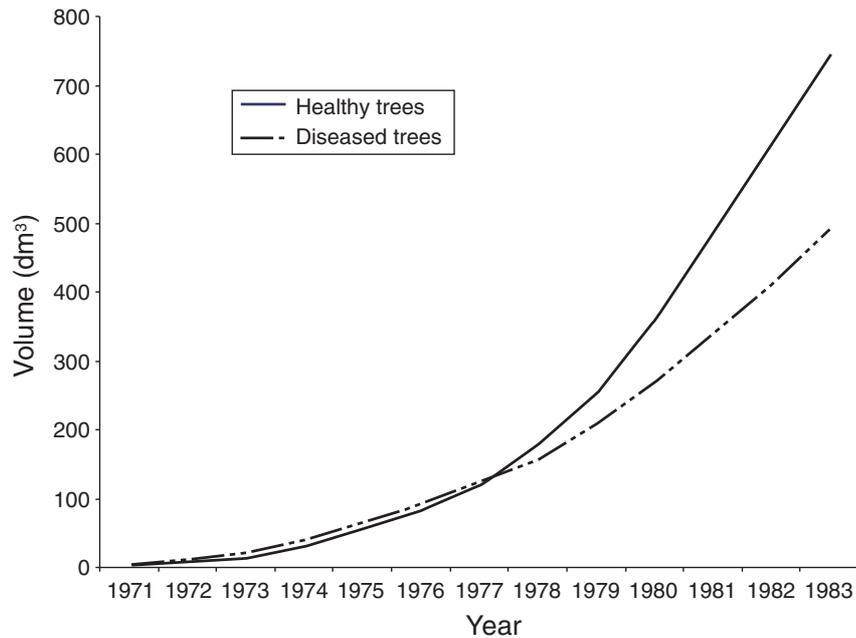
FIG. 5.1 – Annual volume (dm³/ha) of healthy and diseased trees from 1971 to 1983.

cause changes in the stem form. This was supported by relative diameter series of the 11 trees in each group that were not injected. The diseased trees show diameter growth in the bottom part of the stem reduced by about 3%, relative to healthy trees. This is in agreement with earlier findings of the effect on stem form of (a) defoliation caused by *D. pini* (Whyte 1976; van der Pas 1981) and (b) partial defoliation (Rook & Whyte 1976). It seems reasonable to expect, however, that a nominal effect on stem taper will not seriously restrict the use of the Kaingaroa Growth Model (*see* Chapter 6) for increment predictions.

Relationships between disease severity and loss in volume increment

A stepwise regression analysis of the annual volume increments on initial tree size and annual disease severity of current and previous years was performed for each year from 1977 to 1983. The average disease severity of previous years was successively added to the regression equation until the added variable failed to make a significant contribution at a 5% level. The best-fit models were provided by adding only the current annual disease severity to the volume of the penultimate year. The disease severity of the previous years removed no significant variation when added to the equation.

This may not be surprising because the peak period of needle-cast occurs in spring 3–6 months after the infection of the current needles which are, at that time, about 8–9 months old (Gadgil 1984), and so may directly affect the current year's wood production. The effect of previous years' defoliation, however, may be concealed since annual disease severity levels were highly correlated and growth response may extend over more than 1 year. Therefore, the average disease severity was taken for the 6-year period from 1978 to 1983 and related to the volume increments of that period. This gave a satisfactory linear relationship (Fig. 5.2).

The scattergram exhibits some variation, which is attributable mainly to inaccurate disease assessments and competition effects, but it shows that growth during the 6-year period was severely reduced by the disease. Volume increment reduction at an average disease level of 80% was approximately 60% of that of the increment of healthy trees. This is in agreement with findings by Rook & Whyte (1976) who reported a reduction of 50% in volume increment after removing 1- and 2-year-old needles. The slightly higher growth reduction in this experiment may be attributed to the compounded effect of defoliation for 6 consecutive years.
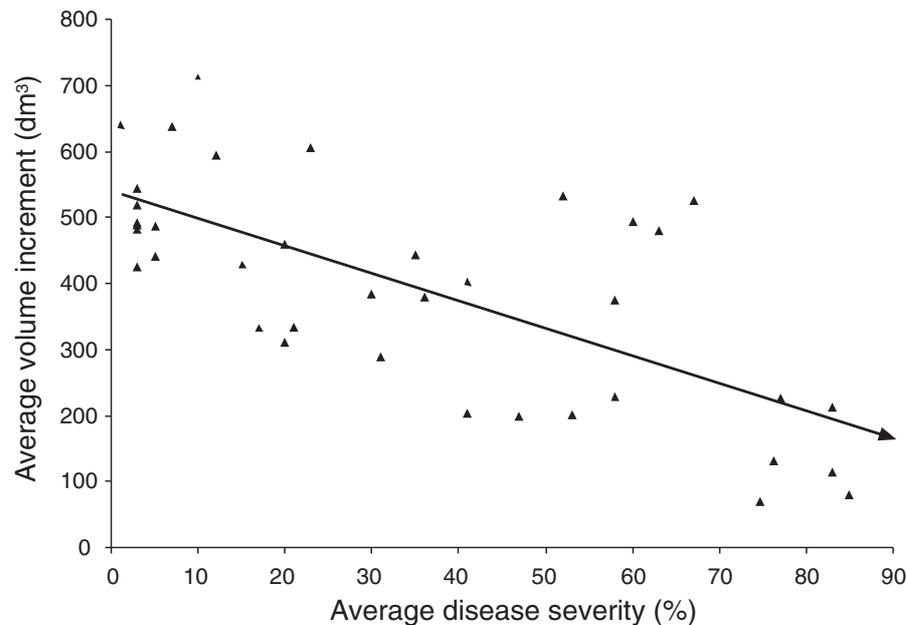
FIG. 5.2 – Average volume increment as related to the average disease severity for the period from 1978 to 1983. The regression line is of the form Y = 537 – 4.29X (N = 38, R^2 = 0.54), where Y = volume increment (dm^3), and X = disease severity (%).

(b) Diameter Growth

Abstract

During October and November 1994, trials to test the effect of needle-cast caused by *C. minus* on growth of *P. radiata* were established at Otago, Nelson, Wellington, East Cape, and Auckland. An additional trial was established in Northland in 1995. In 1994 and 1995, disease was not apparent at Nelson and the East Cape, plot trees were selected at these sites in November 1996. At Auckland, disease levels of the susceptible trees averaged 67% from 1994 to 1999, compared with 12% for the "healthy" trees. Respective increments were 95 mm and 157 mm, a difference of 62 mm over 5 years. Growth differences were obvious at Northland where the susceptible trees grew 81 mm compared with 107 mm for the "healthy" trees over 4 years. At Wellington the trees chosen as susceptible had average disease levels of 58% (1994-99) compared with 6% for the "healthy" trees and respective increments were 73 mm and 121 mm. Cyclaneusma needle-cast significantly reduced growth of individual trees at these sites. When regressions of increment and disease levels from Auckland and Wellington were compared, the intercepts were significantly different but the slopes were similar, suggesting that the effect of disease on diameter increment was the same at both sites. An average disease level of 60% over 6 years resulted in a 50% diameter increment loss.

5.4 INTRODUCTION

This section describes the results of a series of trials established to supplement the trial on the effect of disease on volume growth described in the previous section. The aerial survey of Cyclaneusma that was carried out over 3 years from 1983 to 1985 (Bulman 1988) found regional differences in disease incidence and severity (*see* Chapter 4). So, in 1994 trials were established at five locations in New Zealand to examine the effect of Cyclaneusma needle-cast on diameter growth of *P. radiata* and to compare disease-growth loss relationships between regions.

5.5 METHODS

Site selection

In 1994, trial sites were selected at Cpt 37 Otago Coast Forest; Kainui Forest, Pascoes Block (Nelson); Puketiro Forest, Cook Block (Upper Hutt); Cpt 11 Ruatoria Forest; and Cpt 6160 Stand 5 Mahurangi Forest (Auckland). In 1995, an

additional trial was established at Cpt 4139 Mamaranui Forest approximately 20 km north-west of Dargaville. Severe outbreaks have been recorded from these regions over the last 10 years (Ministry of Forestry, unpubl. Forest Health records). Plots were established in 6- to 7-year-old stands, after they had received a first thinning. In 1994, only one compartment in Otago Coast Forest had significant levels of the needle-cast. Symptoms associated with the disease were not apparent at Ruatoria and Nelson in 1994 or 1995. Plots were established at these two areas in 1996, and in Nelson the site was changed from Pascoes Block to Rabbit Island. Silvicultural regimes were similar on all sites, to eliminate confounding silvicultural effects with growth-disease loss relationships. Particulars of each site are given in Table 5.4.

Plot size and layout, measurements

Plots were established during October and November. In each plot between eight and 11 healthy trees (crown free from any visible infection) and eight and 11 heavily diseased trees (over 60% of the crown affected by the disease) were selected. The number of trees per plot was dependent on how many heavily diseased trees were available for selection at each site. Trees with abnormal form or atypical site characteristics were avoided. Trees were numbered with permalat tags and bands were painted around the stem at breast height.

During the time of peak symptom expression (September to November, depending on the region) each plot tree was measured for diameter at breast-height (dbh) and was assessed by the same assessor every year for disease severity using the 5% step method used for the assessment of Dothistroma needle-blight (Kershaw *et al*. 1988).

5.6 RESULTS AND DISCUSSION

Disease susceptibility

Correlation analysis was undertaken for annual disease levels of the three trials with 6 years' data (Mahurangi, Wellington, and Otago Coast). Annual disease levels of individual trees were highly correlated for the 6 years (Table 5.5). Disease levels at the remaining trials were also highly correlated (correlation coefficients ranged between 0.678 and 0.892 for the trials with 4 and 5 years' data). This shows that the susceptibility of trees to the fungus remains constant over time, and that it is possible to select disease-susceptible trees at the onset of the disease (when the trees are 6 to 7 years old).

Effect of disease on diameter growth

The average sizes of trees selected as susceptible and healthy were similar when the trees were first measured. Since the initial measurements, growth

TABLE 5.4 – Trial site details and plot size.

Location	Biological region	Planting year	Plots first measured	No. of plots	Trees/plot
Otago Coast Forest	Dunedin	1985	1994	4	16
Rabbit Island	Nelson	1986	1996	4	20
Puketiro Forest	Wellington	1987	1994	5	20
Ruatoria Forest	Gisborne	1987	1996	5	20
Mahurangi Forest	Auckland	1988	1994	5	20
Mamaranui Forest	Northland	1988	1995	6	20

TABLE 5.5 – Correlation coefficients between annual disease levels from 1994 to 2000.

Year	1994	1995	1996	1997	1998	1999
1995	0.845					
1996	0.876	0.887				
1997	0.845	0.853	0.860			
1998	0.782	0.809	0.831	0.793		
1999	0.819	0.809	0.848	0.826	0.865	
2000	0.794	0.744	0.815	0.798	0.811	0.890

of the trees selected as susceptible has been reduced through the effects of consecutive years of needle-cast (Fig. 5.3; Tables 5.6 and 5.7). At Mahurangi, disease levels of the susceptible trees averaged 64% from 1994 to 2000, compared with 12% for the "healthy" trees. Respective increments were 112 mm and 184 mm, a difference of 72 mm over 6 years. Growth differences were obvious at Mamaranui where the susceptible trees grew 90 mm compared with 123 mm for the "healthy" trees over 5 years. At Puketiro Forest the trees chosen as susceptible had average disease levels of 57% (1994–2000) compared with 6% for the "healthy" trees. Diameter increment from 1994 to 2000 was 85 mm for the susceptible trees and 144 mm for the "healthy" trees. Otago Coast Forest had lower disease levels of 29% for susceptible trees, and 6% for "healthy" trees, with respective increments of 128 mm and 144 mm.
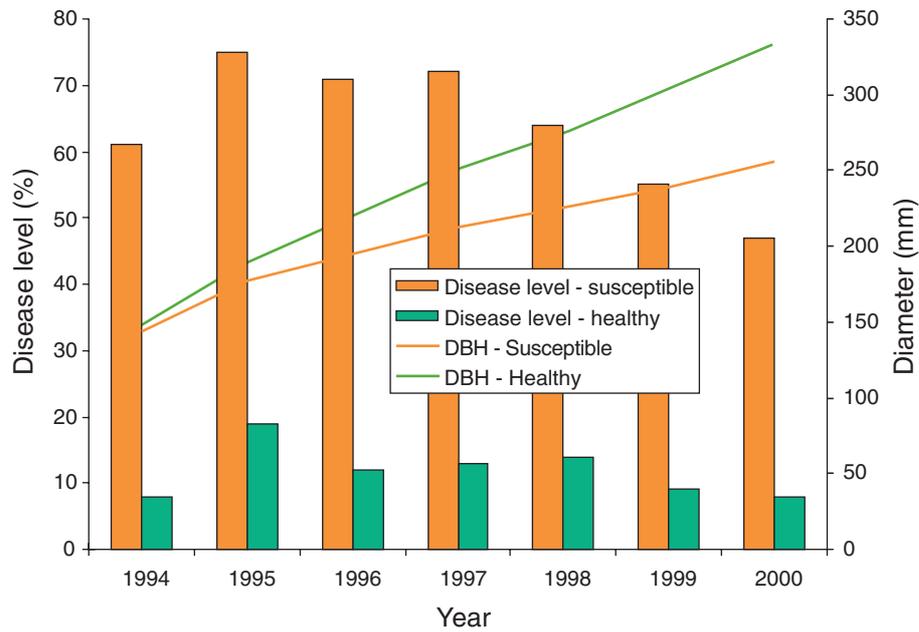

FIG. 5.3 – *Cyclaneusma* disease levels and diameter growth of *P. radiata* at Mahurangi

TABLE 5.6 – Diameter-at-breast-height (dbh) assessments of diseased and healthy trees

Location	Dbh (mm) of diseased trees							Dbh increment (mm) of diseased trees					
	1994	1995	1996	1997	1998	1999	2000	1994 –95	1995 –96	1996 –97	1997 –98	1998 –99	1999 –00
Diseased trees													
Mamaranui		266	291	317	331	345	356		25	25	14	14	11
Mahurangi	144	177	195	213	225	239	256	32	18	18	12	14	17
Ruatoria			247	263	281	309	335			17	18	28	26
Puketiro	168	188	207	219	230	241	253	20	19	12	11	11	12
Rabbit Island			209	223	239	254	268			15	16	15	14
Otago Coast	217	245	266	287	309	327	345	27	22	21	22	18	18
Healthy trees													
Mamaranui		268	302	335	355	376	391		33	33	20	21	16
Mahurangi	147	190	219	251	275	303	332	43	29	32	24	27	29
Ruatoria			241	262	283	316	350			21	22	33	33
Puketiro	164	188	218	238	263	285	308	24	31	20	25	22	23
Rabbit Island			215	230	248	266	281			17	18	18	15
Otago Coast	216	245	270	295	321	341	360	29	25	26	25	20	19

TABLE 5.7 – Disease assessments (percentage of foliage diseased) of diseased and healthy trees

Location	Diseased trees							Healthy trees						
	1994	1995	1996	1997	1998	1999	2000	1994	1995	1996	1997	1998	1999	2000
Mamaranui		70	61	66	51	46	37		7	6	8	9	8	10
Mahurangi	61	75	71	72	64	55	47	8	19	12	13	14	9	8
Ruatoria			55	55	45	39	36			4	5	7	6	4
Puketiro	55	62	62	48	62	57		3	7	6	9	8	7	
Rabbit Island			53	41	40	16	18			3	4	5	4	7
Otago Coast	39	32	31	36	15	19	29	1	3	4	6	4	5	6

For Mahurangi, trees were grouped into three classes where disease levels from 1994 to 2000 averaged 1–30% (41 trees, mean disease level 11%, low disease), 31–60% (13 trees, mean disease level 45%, medium disease), and 61–90% (32 trees, mean disease level 75%, high disease). Diameter growth was calculated for each of the three classes and plotted (Fig. 5.4). In 1994 trees in the low, medium, and high disease classes had dbh of 153 mm, 149 mm, and 138 mm respectively. By 2000, average dbh were 327 mm, 294 mm, and 222 mm respectively.

Disease/growth loss relationships

Stepwise regressions of diameter increment on annual disease levels were carried out. Average annual disease levels of successive years were related to annual diameter increments and only those regressors significant at the 5% level were accepted in the equation. The current annual disease level or the disease level of the previous year generally gave the best fit (Table 5.8). The inclusion of disease levels of more than 2 years before the increment period removed no significant variation from the model. However, significance may have
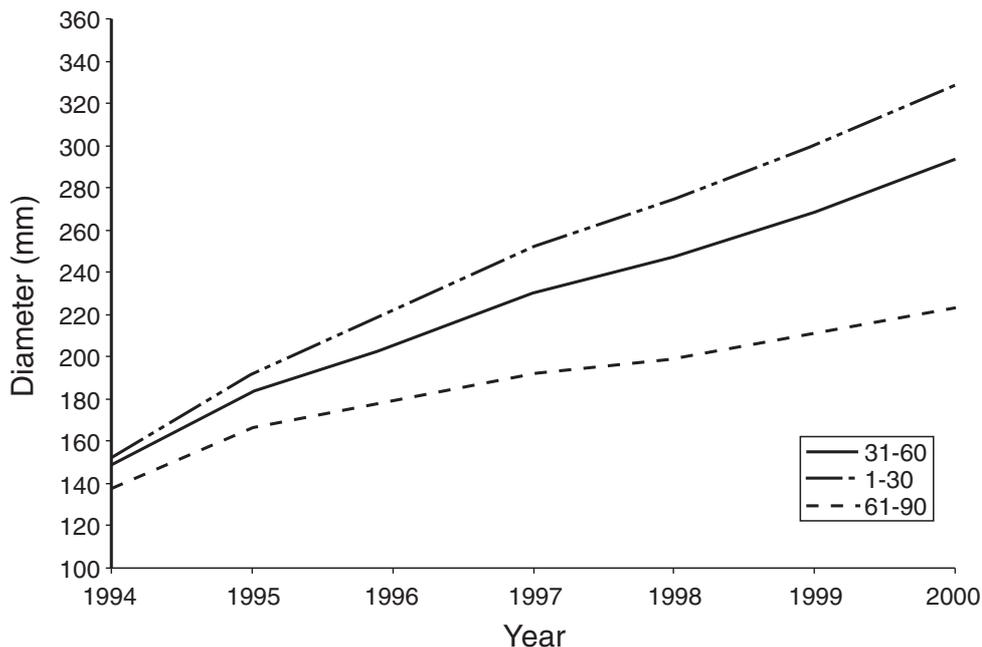

FIG. 5.4 – *Cyclaneusma* **disease levels and diameter growth of** *P. radiata* **at Mahurangi by disease class**

TABLE 5.8– Regression coefficients for diameter increment on disease level for each location

Location	Increment year	Variable	Intercept	Estimate	Significance	R^2
Kaihu	1996–97	Disease 1997	34.51	–0.132	0.0001	0.177
	1997–98	Disease 1997	20.35	–0.094	0.0001	0.152
	1998–99	Disease 1999	21.68	–0.115	0.0001	0.204
	1999–00	Disease 2000	16.50	–0.134	0.0001	0.203
Mahurangi	1996–97	Disease 1997	35.01	–0.253	0.0001	0.433
	1997–98	Disease 1998	27.35	–0.240	0.0001	0.500
	1998–99	Disease 1998	30.11	–0.253	0.0001	0.507
	1999–00	Disease 1999	31.43	–0.270	0.0001	0.607
Ruatoria	1996–97	Disease 1997	22.52	–0.124	0.0001	0.214
	1997–98	Disease 1998	22.88	–0.122	0.0001	0.182
	1998–99	Disease 1999	35.27	–0.218	0.0001	0.422
	1999–00	Disease 1999	34.84	–0.239	0.0001	0.405
Wellington	1996–97	Disease 1996	21.20	–0.155	0.0001	0.419
	1997–98	Disease 1996	26.07	–0.236	0.0001	0.578
	1998–99	Disease 1998	22.54	–0.187	0.0001	0.551
	1999–00	Disease 1998	24.34	–0.204	0.0001	0.498
Nelson	1996–97	Disease 1997	18.03	–0.093	0.0001	0.202
	1997–98	Disease 1997	19.14	–0.087	0.0002	0.163
	1998–99	Disease 1998	18.70	–0.102	0.0001	0.266
	1999–00	Disease 2000	16.62	–0.187	0.0001	0.229
Otago	1996–97	Disease 1996	25.68	–0.159	0.0001	0.330
	1997–98	Disease 1994	25.70	–0.137	0.0001	0.239
	1998–99	Disease 1999	21.08	–0.172	0.0001	0.227
	1999–00	Disease 1999	20.38	–0.163	0.0001	0.239

been masked as annual disease levels were highly correlated for all years.

There was a satisfactory correlation of disease level and diameter growth at Mahurangi and Wellington. Growth patterns of *P. radiata* (particularly when disease is not severe) are variable and there is some variation associated with disease assessments. Scattergrams are given in Fig. 5.5 of the percentage loss of diameter increment as related to average disease level of the preceding years. The trend lines were conditioned to pass thorough the origin. The effect of the disease on diameter growth was almost identical for Mahurangi and Wellington, as shown by the following regression lines:

Diameter increment loss at Wellington
$$= 0.00 + 0.868 \text{ disease} \qquad R^2 = 0.585$$

Diameter increment loss at Mahurangi
$$= 0.00 + 0.826 \text{ disease} \qquad R^2 = 0.531$$

These diameter increment loss – disease level relationships are not dissimilar to that reported by van der Pas *et al.* (1984a) where a regression line (unpublished data, available from L. S. Bulman) for diameter increment from 1978 to 1982 and average disease level from 1977 to 1981 was:

Diameter increment loss at Kaingaroa
$$= -0.002 + 0.765 \text{ disease} \qquad R^2 = 0.666$$
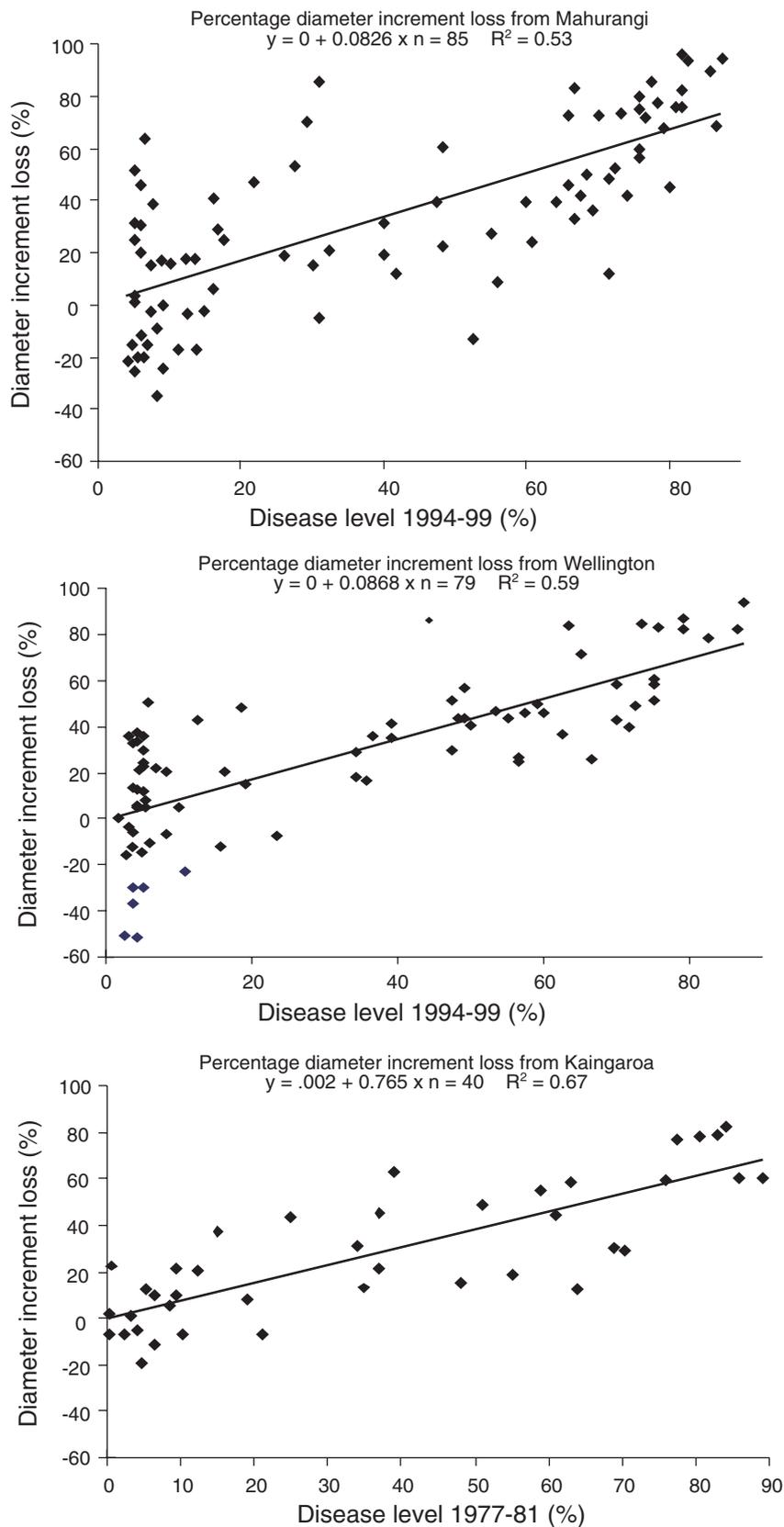
FIG. 5.5 – **Average disease level and diameter increment loss at Mahurangi, Wellington, and Kaingaroa**

These data show that *Cyclaneusma* has a significant effect on growth of disease-prone trees. At the sites where diseased trees were subjected to high levels of Cyclaneusma needle-cast over successive years, diameter growth was noticeably reduced.

Susceptibility to the disease remained relatively constant over time as demonstrated by the correlation of annual disease levels. The effect of disease on growth did not differ significantly between locations. An average disease level of 60%

over a 6-year period resulted in an average diameter increment loss of 50% at the Auckland trial and 52% at the Wellington trial. These results are consistent with those found in the Kaingaroa trial reported by van der Pas, Slater-Hayes, Gadgil. & Bulman (1984), although the diameter increment loss was lower at Kaingaroa. The Kaingaroa trial data were taken over a 4-year period, which may account for the lower increment loss value.

The diameter increment losses associated with Cyclaneusma needle-cast found in this study are significantly higher than diameter growth losses from defoliation caused by *Dothistroma pini* reported by van der Pas (1981). However, infection levels of *D. pini* in the diseased trees selected in the van der Pas (1981) trial were much lower (average 41% over 4 years) than average infection levels of *Cyclaneusma* assessed in the Mahurangi or Wellington trials (64% and 57% over 7 years, respectively). *Dothistroma pini* usually infects foliage younger than 6 months old whereas *Cyclaneusma* can infect only older (8 to 9 months old) needles. Rook & Whyte (1976) found that artificial defoliation of current (0- to 1-year-old) foliage resulted in greater increment loss than defoliation of 1- to 2-year-old foliage. It is therefore likely that an average *D. pini* infection level of 50% over a 6-year period will result in a greater increment loss than *Cyclaneusma* infection of similar severity and duration. Although *Cyclaneusma* causes defoliation of only 1- to 2-year-old foliage, it still causes a significant growth reduction.

Disease severity at the Nelson and Otago trials was lower than that noted in the trials established at Northland, Auckland, East Cape, and Wellington. However, the few highly-diseased trees selected at the Nelson and Otago trials demonstrated significant growth loss. The effect of disease on growth has been demonstrated for individual trees, but no attempt has been made to estimate growth loss on a stand basis. Growth compensation effects with healthy trees taking advantage of the increased growing space made available by heavily diseased trees were probably not significant because crown closure did not occur. Also, it is unlikely that such compensation effects will be important in managed stands, because the disease is most severe when trees are aged between 11 and 20 years old — by which time plantations should be at their final-crop stocking.

Nationally, approximately 10% of trees aged between 11 and 20 years old had disease severity levels of over 40% (Bulman 1988) but on some sites the incidence and severity of the disease was much higher. At these sites over 40% of the trees had disease levels of over 60% (unpublished data, available from L.S.Bulman). Because disease levels are highly correlated over time, it is reasonable to assume that susceptible trees would be subject to an average disease level of 60% from age 6 to about age 20. This could lead to an approximate 50% diameter growth loss for this component of the crop.

6. ECONOMIC IMPACT OF THE DISEASE

L. S. Bulman

Abstract

Stand growth was projected to age 30 for various proportions of diseased trees. For each 10% increase in the proportion of diseased trees a reduction in total volume of 10–14 m³/ha and a subsequent reduction in revenue at clearfelling of $600–$700/ha is predicted when disease severity of affected trees averages 59% over a 6-year period. When 50% of the crop is diseased, a reduction in revenue of between $3,200/ha and $3,600/ha may be expected.

Losses in wood volume, attributable to the disease, of 5% per annum in the forests sampled during the aerial surveys were predicted for stands aged between 6 and 20 years. Growth losses of 6.6% per annum for the *Pinus radiata* estate aged between 6 and 20 years were estimated and financial loss due to the disease is estimated to be of the order of $51 million per annum.

6.1 INTRODUCTION

Sweet (1989) and New (1989) estimated economic losses due to diseases over the New Zealand forest estate. Sweet extrapolated the percentage loss figures of van der Pas, Bulman, & Slater-Hayes (1984) to an economic loss over the entire estate of $41.4 million, and then divided the figure by 3 to allow for compensation (even though he stated that there would be little compensation) and regional variation (although regional variation was accounted for by selecting forests with a range of disease severities). He estimated that increment losses from Armillaria root disease cost $3.6 million per annum, and that increment losses from Dothistroma needle-blight were insignificant because of regular aerial spray applications of fungicide. Therefore, economic losses from Dothistroma needle blight amounted to the cost of spraying only, approximately $1.2 million per annum. New, on the other hand, estimated cost of *Dothistroma* control at $1.6 million and a further $4.5 million annual loss from growth reduction. Van der Pas, Bulman, & Slater-Hayes (1984) and Bulman (1988) did not attempt to put a monetary value on national losses as a result of Cyclaneusma needle-cast.

These examples demonstrate that it is difficult to put a precise figure on economic losses due to diseases. Nevertheless, an attempt has been made to provide a gross approximation of losses from Cyclaneusma needle-cast on a stand basis and a national basis using data given in previous chapters.

6.2 ECONOMIC IMPACT ON A STAND BASIS

No data are available on the final yield of a diseased stand which can be used for an economic evaluation of growth losses attributable to Cyclaneusma needle-cast. Data from the volume loss trial described in Chapter 5 were therefore used to derive the final yields. Volume growth was calculated for healthy and diseased stands. For diseased stands, volume reductions were predicted for stands with increasing proportions of diseased trees in 10% steps to 60%, assuming no further impact by the disease after age 15 (Table 6.1). Stand basal areas were extrapolated from the basal area of healthy and diseased trees measured at age 15, and basal areas of diseased stands were reduced proportionally with increased percentage of diseased trees. The Kaingaroa Growth Model (Elliott & Goulding 1976) was used for growth projection to the end of the rotation at age 30, and predictions were carried out for stockings of 400 stems/ha, 300 stems/ha, and 200 stems/ha. Program PROD (Goulding & Shirley 1978) was used to forecast tree size distribution and program SILMOD (Whiteside & Sutton 1983) to predict changes in the net value of the simulated stands.

Disease progress after age 15 and its subsequent impact on growth are difficult to predict and assumptions have to be made to accommodate further analysis. It seems reasonable to expect continuation of infection after age 15 at least for some years. Stands can show severe disease symptoms at ages up to 25 years (van der Pas, Bulman, & Slater-Hayes 1984; Bulman 1988). On these grounds, growth loss in diseased stands at the end of the rotation may be under-estimated. Conversely, growth of healthy stands and of stands with less than 50% of the trees infected may be over-estimated since competition effects were not taken into account. This in turn may lead to an over-

TABLE 6.1 – Volume prediction at age 30, top ht 40 m, of stands* with increasing percentage of diseased trees

Diseased trees (%)	Basal area (m²/ha)	Mean dbh (cm)	Volume (m³/ha)
400 stems/ha			
0	61.8	45.6	812
10	61.0	45.2	793
20	60.0	44.8	780
30	58.9	44.4	766
40	58.0	44.1	753
50	57.0	43.7	741
60	56.0	43.3	728
300 stems/ha			
0	60.4	51.2	797
10	59.4	50.7	784
20	58.5	50.3	772
30	57.5	49.9	758
40	56.5	49.4	745
50	55.6	49.0	733
60	54.5	48.6	719
200 stems/ha			
0	55.9	59.7	723
10	55.1	59.2	713
20	54.3	58.8	702
30	53.4	58.3	691
40	52.6	57.9	680
50	51.6	57.4	668
60	50.8	56.9	657

* Clearwood regime – site index 30; pruned at ages 5, 7, and 9; thinned at ages 5 and 9.

estimation of growth loss. Growth projections were carried out on the basis that the opposite effects are of similar magnitude and cancel out.

Growth projections were based on volume loss caused by the observed disease severities in the volume loss trial (Table 5.1). For a regime of 400 stems/ha a total volume loss of 71 m³/ha was predicted at age 30 if 50% of the final-crop trees were diseased. When silvicultural regimes of 300 stems/ha and 200 stems/ha were similarly modelled with increasing proportions of diseased trees, total stand volume losses due to the disease decreased only slightly with decreasing number of stems per hectare. By running the projected yield data through program PROD, the contribution by log size changed noticeably, i.e., 25% fewer logs over 40 cm s.e.d. and an over-all 8–10% reduction in total harvested volume with increasing proportion of diseased trees. The financial impact of reduced yields on the net value of the stand was predicted by implementing the yield data in program SILMOD to show the approximate revenue losses that could be expected in stands with similar conditions. It must be remembered that the values and costs used in SILMOD vary considerably depending on stand conditions, market assumptions, and other factors (the options selected in this study are given in Table 6.2); the use of other growth models may produce different results.

The reduction of revenue at clearfelling increased by approximately $600–$700/ha for each 10% increase in the proportion of diseased trees (Table 6.3). When 50% of the final-crop trees were diseased, the reduction in revenue ranged from $3200/ha to $3600/ha. Differences in revenue between the silvicultural regimes were small.

TABLE 6.2 – Selected variables for program SILMOD

Price for 100×50-mm No. 1 framing grade	$147.42/m^3$
Price for delivered pulpwood	$25.29/m^3$
Price for chip residue	$15.17/m^3$
Minimum s.e.d.	200 mm
Conversion factor	52.6%
Conversion standard	Average 2 mm overcut, 2.4 m min. length
Consumer price index	1369
Discount rate	10%
Harvesting method	Skidder
Distance from forest to mill	50 km
Thinning cost – first	$165/ha
Thinning cost – second	$62/ha
Pruning cost – first	$244/ha
Pruning cost – second	$185/ha
Pruning cost – third	$178/ha

TABLE 6.3 – Changes in stand worth resulting from changes in harvestable volume and log-size distribution in stands with increasing percentage of diseased trees (using SILMOD)

Diseased trees (%)	Net decrease in total volume (m³/ha)	Net decrease in harvestable volume (m³/ha)	Total cost ($/ha)	Total revenue ($/ha)	Net decrease due to disease ($/ha)
400 stems/ha					
0			56 800	56 100	
10	19	16	55 500	54 100	700
20	32	27	54 900	52 900	1 300
30	46	38	54 300	51 700	2 000
40	59	47	54 300	51 000	2 600
50	71	58	53 800	49 900	3 200
60	84	67	53 400	48 900	3 800
300 stems/ha					
0			53 000	56 600	
10	13	11	52 600	55 500	700
20	25	20	52 200	54 500	1 400
30	39	30	51 700	53 300	2 100
40	52	41	51 800	52 500	2 900
50	64	49	51 400	51 500	3 500
60	78	61	50 900	50 200	4 300
200 stems/ha					
0			45 700	54 300	
10	10	8	45 400	53 400	700
20	21	16	45 200	52 400	1 400
30	32	25	44 900	51 400	2 100
40	43	33	44 600	50 500	2 800
50	55	43	44 300	49 200	3 600
60	66	50	44 000	48 400	4 200

Volume loss in the 15 forests surveyed for *Cyclaneusma* needle-cast

Disease incidence and severity data collected from the three aerial surveys were used to estimate the volume loss by age-class of the 15 forests surveyed.

Percentage volume reduction was estimated using the formula:

$$V = 426D/537$$

where V = volume loss (%) and D = disease severity (%). This formula was derived from the regression

of Fig. 5.2. Total area of the 15 forests for each age-class from 1983 to 1985 was calculated using Program SAREA from the NZFS Stand Record System (Shirley 1983.) Annual volume loss for each age-class was calculated by multiplying the area occupied by diseased trees (from Table 4.4) by the periodic annual increment (PAI), which gave the expected volume increment, and volume loss factors derived from the formula above. Areas for each age-class and estimates of volume loss, potential volume, and percentage loss are given in Table 6.4. The accuracy of estimates is open to conjecture; the calculation of percentage loss for each age-class is dependent on disease assessment accuracy and the validity of the volume loss equation only. The PAI and area data are constants, which do not affect the percentage loss figure for each age-class. The mean difference between assessors was of the order of 3%, with the coefficient of variation about 5%. The volume loss formula was derived from a regression line with a coefficient of determination of 0.54.

The volume loss figures are approximations, and cannot be extrapolated to the total estate, but indicate that the volume loss in the 15 forests surveyed would have been of the order of 5% per annum for the age-classes 6–20 years. It is important to note that the 5% per annum figure is an average of all forests surveyed. Volume loss will be much higher for forests on disease-prone locations (Northland, East Cape, central North Island). More stands will fall into the problem age classes in the future as a result of the expanded planting programmes since the early 1990s.

6.3 ECONOMIC IMPACT ON A NATIONAL BASIS

As stated previously, disease severity is variable among forests within regions. In order to provide a precise regional figure for disease incidence and severity a large number of forests would have to be surveyed. Instead, a risk rating using a 1-5 scale was allocated to each region based on results from the aerial surveys, data stored in the Forest Health Database, and personal knowledge. The scale is given in Table 6.5.

Table 6.5 – Risk factor ratings for Cyclaneusma needle-cast

Rating	Average disease incidence	Average disease severity
1	10	20
2	15	25
3	20	30
4	25	45
5	25	55

TABLE 6.4 – Volume loss from forests surveyed from 1983 to 1985

Age (years)	Year	Area* (ha)	PAI (m³) (m³)	Volume loss (m³)	Pot. volume† (m³)	Loss (%)
1–5	1983	49 900	1	200	49 900	0.4
	1984	49 200	1	700	49 200	1.4
	1985	47 200	1	300	47 200	0.6
6–10	1983	52 600	5	7 500	263 000	2.9
	1984	57 100	5	15 800	285 600	5.5
	1985	55 400	5	16 800	276 800	6.1
11–20	1983	50 400	21	45 900	1 057 600	4.3
	1984	62 300	21	70 600	1 309 100	5.4
	1985	70 000	21	94 600	1 470 000	6.4
21–25	1983	9 500	34	7 000	322 660	2.2
	1984	11 700	34	8 300	397 800	2.1
	1985	14 400	34	16 700	489 600	3.4
>25	1983	20 000	32	1 300	639 400	0.2
	1984	18 700	32	1 100	597 100	0.2
	1985	18 300	32	7 700	585 300	1.3

* Total net stocked area of the 15 forests surveyed
† Potential annual volume increment if disease was at trace levels

Area of plantation forest aged between 6 and 20 years for each wood supply region by Territorial Authority (Ministry of Agriculture and Forestry 2000) is given in Table 6.6 (*see* Appendix 3 for a map showing the regions). Volume loss was calculated for each region by using the volume loss formula $V = 426D/537$ described above to estimate percentage volume loss for each disease severity associated with the risk ratings. The volume loss figure was then multiplied by the respective incidence and area to obtain an estimate of the annual volume loss for each region. This figure was then multiplied by the mean annual increment (taken to be 20/m³/ha) and a stumpage of $50 to derive loss estimate in dollar terms. For instance, the Far North district was given a risk factor of 4. The percentage volume loss from an average disease severity of 45% is 35.7%. This value was then multiplied by 25% (the disease incidence for risk factor 4) to give an annual volume loss figure of 8.93%. The area of susceptible *P. radiata* planted in the Far North district is 50 779 ha; therefore the economic loss is estimated at 50 779 ha × 20/m³/ha × $50 × 8.93% = $4.53 million.

TABLE 6.6 – Regional area, risk, and loss from Cyclaneusma needle-cast

Region / Territorial Authority	Area*	Risk factor	Loss (%)	Loss ($)
Northland				
Far North District	50 779	4	8.9	4 532 000
Whangarei District	19 780	5	10.9	2 158 000
Kaipara District	23 621	5	10.9	2 577 000
Rodney District	11 329	5	10.9	1 236 000
Total	**105 509**		**10.0**	**10 502 000**
Auckland				
Waitakere City	12	4	8.9	1 000
Auckland City	105	4	8.9	9 000
Manukau City	2 398	4	8.9	214 000
Franklin District	4 192	4	8.9	374 000
Thames-Coromandel District	11 337	3	4.8	540 000
Hauraki District	958	3	4.8	46 000
Waikato District	5 108	3	4.8	243 000
Matamata-Piako District	598	3	4.8	28 000
Total	**24 708**		**5.9**	**1 455 000**
Central North Island				
Hamilton City	72	3	4.8	3 000
Waipa District	867	3	4.8	41 000
Otorohanga District	1 143	3	4.8	54 000
South Waikato District	32 125	4	8.9	2 867 000
Waitomo District	4 980	3	4.8	237 000
Taupo District	94 418	4	8.9	8 426 000
Tauranga City	121	3	4.8	6 000
Ruapehu District	21 639	2	3.0	644 000
Western Bay of Plenty District	15 320	3	4.8	729 000
Rotorua District	22 928	4	8.9	2 046 000
Whakatane District	53 194	3	4.8	2 532 000
Opotiki District	14 911	4	8.9	1 331 000
Total	**261 718**		**7.2**	**18 917 000**
East Coast				
Gisborne District	75 652	5	10.9	8 252 000
Total	**75 652**		**10.9**	**8 252 000**
Hawke's Bay				
Wairoa District	21 174	4	8.9	1 890 000
Hastings District	23 160	2	3.0	689 000
Napier City	150	2	3.0	4 000
Central Hawke's Bay District	3 801	2	3.0	113 000
Total	**48 285**		**5.6**	**2 696 000**

TABLE 6.6 – continued

Region / Territorial Authority	Area*	Risk factor	Loss (%)	Loss ($)
Southern North Island				
New Plymouth District	2 239	4	8.9	200 000
Stratford District	3 031	4	8.9	271 000
South Taranaki District	3 923	4	8.9	350 000
Wanganui District	9 525	3	4.8	453 000
Rangitikei District	5 117	2	3.0	152 000
Manawatu District	2 663	2	3.0	79 000
Palmerston North City	935	2	3.0	28 000
Horowhenua District	3 418	2	3.0	102 000
Tararua District	3 492	2	3.0	104 000
Kapiti Coast District	1 585	2	3.0	47 000
Upper Hutt City	3 201	4	8.9	286 000
Porirua City	1 468	3	4.8	70 000
Wellington City	275	3	4.8	13 000
Lower Hutt City	104	3	4.8	5 000
Masterton District	14 837	3	4.8	706 000
Carterton District	2 915	2	3.0	87 000
South Wairarapa District	2 520	2	3.0	75 000
Total	**61 248**		**4.9**	**3 027 000**
North Island total	**577 120**		**7.8**	**44 850 000**
Nelson and Marlborough				
Tasman District	37 120	2	3.0	1 104 000
Nelson City	3 686	2	3.0	110 000
Marlborough District	30 216	2	3.0	899 000
Kaikoura District	379	1	1.6	6 000
Total	**71 401**		**3.0**	**2 119 000**
West Coast				
Buller District	2 922	3	4.8	139 000
Grey District	6 589	3	4.8	314 000
Westland District	2 331	3	4.8	111 000
Total	**11 842**		**4.8**	**564 000**
Canterbury				
Hurunui District	14 711	1	1.6	233 000
Waimakariri District	7 028	1	1.6	112 000
Selwyn District	6 955	1	1.6	110 000
Christchurch City	1 712	1	1.6	27 000
Banks Peninsula District	1 512	1	1.6	24 000
Ashburton District	2 078	1	1.6	33 000
Mackenzie District	2 042	1	1.6	32 000
Timaru District	3 437	1	1.6	55 000
Waimate District	4 020	1	1.6	64 000
Total	**43 495**		**1.6**	**690 000**
Otago and Southland				
Waitaki District	4 117	1	1.6	65 000
Queenstown-Lakes District	85	1	1.6	1 000
Central Otago District	930	1	1.6	15 000
Dunedin City	10 445	3	4.8	497 000
Clutha District	23 428	3	4.8	1 115 000
Southland District	19 098	3	4.8	909 000
Gore District	555	2	3.0	17 000
Invercargill City	393	2	3.0	12 000
Total	**59 051**		**4.5**	**2 631 000**
South Island total	**185 789**		**3.2**	**6 003 000**
New Zealand total	**762 909**		**6.7**	**50 853 000**

*Area of *Pinus radiata* plantations aged 6 to 20 years as at 1 April 1999

The total financial loss attributable to Cyclaneusma needle-cast over the *P. radiata* estate aged between 6 and 20 years is estimated to be $51 million per annum. Volume loss per annum is estimated to be 6.6%. Losses in stands outside this age-class are considered to be negligible. The percentage loss figure conforms with the findings of van der Pas, Bulman, & Slater-Hayes (1984) and Bulman (1988). Individual compartment data (disease incidence and severity assessments) from the three aerial surveys of Mangatu and Ruatoria Forests on the East Cape were used to calculate percentage losses on the same basis as used for Table 6.6. The individual incidence and severity assessments averaged over 3 years for both forests gave a volume loss estimate of 11.2%, which compares closely with the figure of 10.9% for the East Coast given in Table 6.6.

6.4 DISCUSSION

Financial losses of $3,200/ha to $3,600/ha when 50% of the stand is infected by Cyclaneusma were predicted. These losses are probably under-estimates, as growth projections for diseased trees were based on a disease history of only 4 years' duration and it was assumed that disease would have no further effect on growth after age 15. The assumption that not allowing for compensation effects would cancel out any disease effect after age 15 was conservative because it is probable that little compensation will take place in managed stands.

For the 15 forests surveyed by air, growth losses from Cyclaneusma needle-cast were estimated to be of the order of 5% per annum for stands aged between 6 and 20 years. This estimate is lower than the 6.6% estimated for the entire estate because

average disease severity of the forests selected for the aerial survey was lower than the national average. For instance, Golden Downs Forest had low disease levels all 3 years and comprised 15% of the area surveyed, but the Nelson region accounts for 9% of the national estate aged between 6 and 20 years.

The total loss attributable to Cyclaneusma needle-cast of $51 million per annum is of the same order as that Sweet (1989) extrapolated from van der Pas, Bulman, & Slater-Hayes (1984), given that Sweet (1989) used a percentage loss figure of 2.3% for the entire estate of 1.2 million hectares.

Many factors have to be accounted for when evaluating the economic impact of pests or diseases, stumpage value, area affected, effect on growth, and compensation effects, for example. Therefore, the loss figure should not be considered exact but should be viewed as providing an indication of the magnitude of the problem. However, the predicted reductions of revenue and growth loss estimates show that in heavily diseased stands substantial financial losses may be expected and that control of the disease is warranted. Chemical control by spraying or injecting does not seem economical on a large scale mainly because of the high cost of the fungicides and application (*see* Chapter 7). Another option may be to select families genetically improved against needle loss associated with *C. minus.* This approach has already been adopted in the *P. radiata* breeding programme to a limited extent by selection of trees with good needle retention. Silvicultural control, by removing the most susceptible trees in selective thinning operations, appears to be the most promising control option and is discussed in Chapter 8.

PART III:

CONTROL OF THE DISEASE

7. CHEMICAL CONTROL

I.A. Hood and L. S. Bulman

(adapted from I.A.Hood and A.L.Vanner 1984: *New Zealand Journal of Forestry Science* 14: 215–222)

Abstract

Fungicides were screened for ability to control needle-cast of *Pinus radiata* caused by *Cyclaneusma minus*. Undetached shoots were dipped in water-based suspensions at fortnightly intervals for 20 months from the time of flush. Significant improvements in levels of needle retention were achieved with dodine (86% retention), anilazine (76%), benomyl (74%), and dichlone (66%), in comparison with untreated controls (39%). Injections of acidified aqueous solutions of carbendazim into stems of 8- to 10-year-old trees resulted in reductions in foliage yellowing, needle loss, and numbers of *C. minus* colonies isolated from the foliage. Needle loss was reduced two- to three-fold on 0- to 1-year-old shoots after one season of injections; after 2 consecutive years of injections needle loss was reduced seven-fold on 1- to 2-year-old shoots. Yellowing and defoliation were also reduced by injections of the non-fungicidal compounds ortho-phenylenediamine and L-arginine monohydrochloride, implying that not all the effects of carbendazim are a consequence of its fungicidal properties.

Aerial applications of benomyl (0.25 kg/ha) in an emulsion of water (6 litres/ha) and BP crop oil (4 litres/ha) in June and July failed to check the disease in a 10-year-old *P. radiata* plantation. In a second trial, six monthly aerial applications of dodine from April to August reduced disease incidence and severity but the high cost of spraying could not be justified by the small reduction in disease levels.

7.1 INTRODUCTION

Cyclaneusma needle-cast has a widespread distribution and its impact on stand growth can be severe (van der Pas, Slater-Hayes, Gadgil, & Bulman 1984; van der Pas, Bulman, & Slater-Hayes 1984). It is therefore desirable that a reliable method of control be developed. Exploratory trials were established to determine the effectiveness of different fungicides in controlling the disease. Three methods of application were tried. In one experiment a selection of fungicides was screened for ability to protect new foliage by dipping single shoots. In another, the systemic fungicide, carbendazim, was injected into tree stems to test its ability to prevent disease. The effects of injecting two non-fungicidal compounds were also evaluated during this trial. In the third experiment control of the disease was attempted in a stand of *P. radiata*

at Puruki by aerial applications of benomyl. In 1985, an aerial spray trial using dodine was carried out at Whakarewarewa Forest.

7.2 FUNGICIDE SCREENING TRIAL

Methods

This experiment was started in 1978, in a low-pruned 10-year-old *P. radiata* stand established from grafts of one clone (FRI 121) which is known to be particularly susceptible to the disease. The trees in this stand had deep crowns, as a result of early thinning to 500 stems/ha. At age 10 years the treated trees averaged 14 m in height and 20 cm dbh. Ten shoots located 2.5 to 3 m above the ground were selected from the bottom whorl of each of 10 trees. Treatments were conducted at fortnightly intervals for 20 months, beginning in July at the onset of new shoot extension. Each shoot was dipped in one of nine aqueous fungicide suspensions, the tenth shoot being left untreated as a control (Table 7.1).

Needle retention was evaluated as a measure of treatment effectiveness. Assessments were made 9 months (in April 1979) and 18 months (in January 1980) after treatments began. At each assessment a count was made of the number of needles still retained on the section of the stem produced and treated during the first season (distinguished from other shoot growth by marks). Numbers of needles counted in January were expressed as percentages of the numbers present the previous April to give needle retention level. On average, 110 (range 31–221) needles were counted per shoot in April, when foliage was still less than 1 year old.

Results and discussion

Disease symptoms were first observed in May, 10 months after treatments began, but did not intensify until August. Most diseased foliage fell in September and early October (spring) but needles still retained on treatment shoots the following January were green. Values of needle retention are ranked in Table 7.1 in order of fungicide effectiveness. Needle counts could not be made on

TABLE 7.1 – Results of fungicide screening trial, in order of effectiveness

Treatment*	Concentration (g/litre)	Needles retained† (%)
Dodine	0.65	86 ± 9 a
Anilazine	1.00	76 ± 10 ab
Benomyl	0.25	74 ± 13 ab
Dichlone	0.50	66 ± 15 ab
Maneb	1.60	63 ± 18 b
Chlorothalonil	1.50	61 ± 23 b
Captan	1.60	60 ± 23 b
Untreated control	-	37 ± 18 c
Oxycarboxin	0.75	35 ± 17 c
Copper oxychloride	2.00	-

* Triton X-77 surfactant was added to all fungicide treatments at 1 ml/litre
† Means and 95% confidence limits are shown. Values linked by a common letter are not significantly different
   (p>0.05; Duncan's multiple range test).

shoots treated with copper oxychloride as regular dipping led to shoot death. There was considerable between-tree variation for different treatments, as indicated by the high confidence limits. Despite this, differences between treatments were significant. Greatest control of disease was achieved using dodine, anilazine, benomyl, and dichlone. Only oxycarboxin failed to give some control. Kistler & Merrill (1978) and Merrill, Kistler, & Bowen (1980) have demonstrated fungicidal activity against *C. minus* by benomyl and mancozeb.

7.3 TREE INJECTION EXPERIMENT

Methods

The fungicide carbendazim and two non-fungicidal compounds, *ortho*-phenylenediamine and L-arginine monohydrochloride, were injected into the stems of *P. radiata* trees, and levels of disease control evaluated. Twenty-one trees were selected in the stand previously described (FRI Clone 121). Treatments commenced in 1976, when trees were 8.5 years old and continued for 3 years, the two non-fungicidal compounds being injected in the third growth season only (Table 7.2). Carbendazim (3.5 to 4 g/litre), *ortho*-phenylenediamine (3 g/litre), and L-arginine monohydrochloride (3 g/litre), made up in 0.1N hydrochloric acid, were injected at a rate of approximately 4 litres/tree at each injection. The treatment solution was introduced into the sap stream of each tree at five points around the stem just above ground level, and supply was maintained by gravity feed *(*for details of technique, *see* Hood & van der Pas 1979). Uptake times for 4 litres of the injected solutions varied from 3 hours to 4 days.

Each tree received 2.9 to 3.8 g of bound nitrogen per injection, regardless of the chemical employed.

Two evaluations of foliage retention were made during the experiment. Foliage was collected during November-December (early summer) 13 months after the first treatment in each of the second and third seasons. Eight side shoots were sampled per tree; they were cut at comparable positions from north- and south-facing main branches one-third and two-thirds up the tree stem. In the laboratory, counts of needle fascicles and fascicle scars were made from one or more spiral sets along the full length of each internode, in order to determine the percentages of different age-class foliage retained. Fungal isolations from all trees were carried out in October, 11 months after the first treatment in the third season. Isolations were made from needle segments plated on to 3% malt agar, after 3 minutes' surface sterilisation in 10 vol. hydrogen peroxide. Only one segment (1–1.5 cm long) was plated from each needle.

Results and discussion

No foliar symptoms of phytotoxicity were seen after treatment, but narrow longitudinal cankers eventually developed from injection sites on some trees after several years. Results of the foliage retention assessments are given in Table 7.2.

Treatments had a marked effect on the colour and density of tree crowns. Foliage of injected trees remained green during spring, whereas the foliage of untreated trees became chlorotic and was subsequently cast. Chlorosis reappeared on two trees when carbendazim was not injected again the

TABLE 7.2 – Mean percentage fascicle retention after tree injection

Treatments	Second growth season Foliage age (years)		Third growth season Foliage age (years)	
	1	2	1	2
Injected with carbendazim	54	23	88	42
Injected with L-arginine	-	-	90	-
Injected with *o*-phenylenediamine	-	-	70	-
Not injected	17	3	38	6

following season. Within-treatment differences in needle retention were highly significant ($p < 0.001$), but this did not mask the treatment effect. Carbendazim significantly increased retention of l-year-old foliage (Table 7.2), and when injected for two successive seasons caused an increase in retention of 2-year-old needle fascicles as well. Injections of the other two non-fungicidal compounds also increased l-year-old foliage retention. Cultures of *C. minus* were isolated from non-injected control trees (confirmed in five out of 60 needle segments from five trees) and from trees injected with the two non-fungicidal compounds (in 12 out of 54 needle segments from five trees). *Cyclaneusma minus* was not found in 118 needle segments from 11 trees injected with carbendazim. However, van der Pas, Slater-Hayes, Gadgil, & Bulman (1984) did isolate *C. minus* from trees injected with carbendazim, and so this fungicide does not provide complete control of the fungus.

Injections of carbendazim gave good disease control in young pine trees belonging to one clone. Despite this, it is unlikely that this labour-intensive technique could be used on a management scale, even though the between-tree variation in symptom expression observed in plantations lends itself to a selective approach for fungicide applications. Injecting may have value in studies to elucidate the nature of the host : fungus : fungicide interaction. For instance, treatment with *ortho*-phenylene-diamine and L-arginine monohydrochloride demonstrated that chemicals that are not fungicidal can modify symptoms. The disease symptoms have also been suppressed in smaller trees by heavy ground applications of urea fertiliser (G.M.Will, pers. comm.). All these compounds contain a significant proportion of nitrogen and so their use may correct a nitrogen imbalance induced by the fungus. Benomyl and other benzimidazole fungicides are known to have cytokinin-like properties which may explain their ability to influence foliage coloration (Skene 1972; Thomas

1974; Spencer 1977). Since carbendazim is derived from benomyl, it may also behave in a similar manner in *P. radiata* foliage.

7.4 FIRST AERIAL SPRAY TRIAL

Methods

Aerial spraying is now used routinely for the control of Dothistroma needle-blight in New Zealand pine forests (Kershaw *et al.* 1988). This method of application was therefore tried against *C. minus* in a stand of *P. radiata*. Benomyl was chosen because of the control achieved by this fungicide and carbendazim in the other two experiments.

A 10-year-old *P. radiata* plantation at Puruki in the central North Island, was sprayed with benomyl in an oil emulsion from the air. Oil was added to prevent evaporation of fine droplets while using Micronair spray equipment, and because it had been shown that oil enhances the effectiveness of benomyl in controlling *Dothistroma pini* on nursery-grown *P. radiata* (Gilmour & Vanner 1972). The trial stand was divided into a treatment area of 25 ha and an adjacent unsprayed control area of 8.5 ha. Within each area, four assessment plots of 16 to 27 trees were established at random. Spraying was carried out twice, once on 14 June and again on 15 July. On each occasion benomyl was applied at a rate of 0.25 kg/ha suspended in an emulsion of 6 litres water and 4 litres BP crop oil/ha. Applications were made using a Hughes 300 helicopter, fitted with four Micronair AU 5000 spray units, and application rates were checked immediately before each spray application. Paper traps laid in stand openings confirmed that all the sprayed plots, and none of the unsprayed control plots, were treated. The crown disease level on each tree in the assessment plots was estimated to the nearest 5% on a scale of 0 to 100% of effective green crown remaining. Timing of peak symptom expression varies between trees, so five assessments

of each tree were made over a 2.5-month period, beginning in mid-September. The maximum score for each tree was selected and results were compared by analysis of variance. In addition, at fortnightly intervals from the beginning of June needles were collected from four susceptible trees in the unsprayed area. Isolations were made from these needles as described in previous chapters, in order to determine when the trees became infected by the fungus.

Results and discussion

Estimates of green crown retained are summarised in Table 7.3. There were no significant differences ($p > 0.05$) between means of sprayed and unsprayed areas. *Cyclaneusma minus* was isolated on and after 1 August, but was not found in needles sampled prior to that date.

Failure of the fungicidal treatment could have been caused by too low a fungicide application rate or by incorrect timing, since the fungicide may have given only short-term control. The lack of disease control cannot be a result of late spraying, since *C. minus* was not isolated from needles until after the second application. Life-cycle studies indicate that the infection period of *C. minus* is not consistent from year to year, and may begin as early as March (Gadgil 1984) or as late as July. The occurrence of an extended infection period in some years raises doubt about the suitability of aerial spraying as a practical option for disease control management. However, because the attainment of a practical chemical control method is highly desirable, a second aerial spray trial was carried out.

7.5 SECOND AERIAL SPRAY TRIAL

Introduction

A number of fungicides have been screened for their effectiveness in controlling the disease in the trial described previously and, of those tested, dodine was the most effective. Kistler & Merrill (1978) showed that three applications of mancozeb fungicide gave good control of Cyclaneusma needle-cast in *P. sylvestris* Christmas tree plantations. An aerial spray trial was carried out to evaluate the three fungicides — dodine, mancozeb, and copper oxychloride — for control of Cyclaneusma needle-cast in *P. radiata*.

Methods

Four adjacent treatment plots, each 12.5 ha in size, were established in a 17-year-old stand of *P. radiata* in Whakarewarewa Forest. In 1984 the stand had been rated as having a disease incidence of 40% and a disease severity of 50%. The treatments are listed in Table 7.4. One treatment was assigned to each plot. The fungicides were applied from a helicopter fitted with six Micronair AU 5000 rotary atomisers, and flying at a speed of 60 knots. A spray oil was added to the fungicide mix to assist in slowing evaporation of the small spray droplets produced. Six applications of each fungicide were made at monthly intervals, the first on 1 April 1985 and the sixth on 28 August 1985. For the first application a total spray volume of 5 litres/ha was used but because of difficulties experienced in mixing the mancozeb and oil, and also its poor atomisation, the second and subsequent applications of all treatments were made in a total volume of 10 litres/ha.

Treatment plots were assessed for incidence and severity of visible disease symptoms by the same two experienced observers working from a helicopter on 2 October and again on 29 October 1985. The results of the four assessments of disease incidence and disease severity (two assessments and two observers) were subjected to analysis of variance. Duncan's multiple range test was used to detect any differences in treatment effectiveness.

TABLE 7.3 – Mean percentage level of effective green crown retained* after aerial spraying with benomyl, by plot

	Plot number			
	1	2	3	4
Sprayed	26±12	49±14	32±11	46±11
Unsprayed	37±14	43±14	27±10	23±11

* With 95% confidence limits. Evaluated using a 0–100% assessment scale.

TABLE 7.4 – Mean percentages of green crown retained and disease incidence for each treatment.

Treatment	Fungicide	Application rate (active ingredient/ha)	Disease incidence (%)	Green crown (%)
Dodine	Syllit 40S*	0.8 kg	14 a	65 a
Mancozeb	Mancozeb 80W*	1.6 kg	19 ab	59 ab
Copper oxychloride	Copper oxychloride 50W*	0.8 kg	28 b	40 c
Unsprayed control	-		25 b	50 bc

* Mobil Superior 663 spray oil added at a rate of 2 litres/ha. Treatments joined by a common letter do not differ significantly (p=0.05) using Duncan's multiple range test.

The average expressions of disease severity (expressed as percentage of green crown retained) and disease incidence recorded in each treatment are shown in Table 7.4. The assessments show that only the application of dodine resulted in a reduction of disease incidence and disease severity compared with the unsprayed plot. There was no significant difference between the two assessments or between the results recorded by each observer.

The relationship derived to relate tree growth loss to disease severity was used to estimate the volume response to spraying. If this relationship were to hold true for the trial area, spraying with dodine in 1985 would have resulted in only a 6% increase in stand volume increment. The cost of spraying the dodine treatment by helicopter, exclusive of any ground control costs, amounted to $250/ha for all six applications in 1985. It could be expected that to maintain any reduction in disease, repeated spraying would be necessary, particularly in those years when mild and wet autumn conditions favoured the disease. It is concluded that the high cost of spraying is not justified by the small reduction in disease levels.

8. SILVICULTURAL CONTROL

L. S. Bulman

Abstract

Assessment of a trial with different final crop stockings and varying proportions of unpruned followers showed that stocking density or pruning had no practical effect on incidence or severity of Cyclaneusma needle-cast.

Trials to test the effects of applying five different thinning ratios at five crop ages on the incidence of Cyclaneusma needle-cast were established on two sites at Kaingaroa Forest in 1985. Trees were first thinned at ages ranging from 4 to 9 years, and again at 10 years, when susceptible trees were selected for thinning. Delayed thinning had a significant effect at one site where disease was prevalent. At this site, plots thinned at ages 4 and 5 had mean disease levels over the period 1989 to 1999 of 21% (disease severity exceeded 30% in 28% of the trees) compared with 10% (severity over 30% in only 3% of the trees) for the plots thinned at ages 7 and 8. The early-thinned plots had lower dbh (433.9 mm) than the late-thinned plots (452.6 mm). Treatment differences might have been even greater if disease selection had not been carried out during a second thinning in 1991. Delayed thinning at the other site, which had consistently low disease levels, initially resulted in reduced growth; however, the late-thinned plots outgrew the early-thinned plots during the period since final thinning, thereby eliminating any differences. Delayed thinning with selection for disease-resistant final-crop trees should be beneficial on sites with high disease.

8.1 INTRODUCTION

The cost of disease control in forestry is always a major consideration because of the relatively low annual increase in the value of the crop. Methods of disease control based on the adaptation of normal silvicultural techniques are particularly attractive in this regard. Such methods are likely to be considerably cheaper than chemical control because disease control is only one of the purposes they serve and therefore only a proportion of the cost is chargeable against protection from disease. Silvicultural control measures also cause no environmental damage.

The main silvicultural practices which can be adapted for disease control are:

(a) Stand density: Dense stands provide favourable conditions for the development of some diseases and an open stand may reduce the incidence of such diseases.

(b) Pruning: Pruning may remove heavily infected lower branches, thus lowering inoculum levels of some foliar pathogens and reducing the severity of diseases caused by them.

(c) Thinning: Thinning provides an obvious method of removing diseased trees from a stand and gives the forester one of the best methods of control of some diseases.

The application of these silvicultural techniques to the control of Cyclaneusma needle-cast was investigated. Results of these investigations are given below.

8.2 EFFECT OF CROP DENSITY AND PRUNING

Introduction

The effect of stand density and pruning on disease incidence and severity was examined by assessing all plot trees in a followers trial at Kaingaroa Forest from 1997 to 1999 for Cyclaneusma needle-cast.

Methods

The trial was located in Cpt 1009 at Kaingaroa Forest in 1990 plantings. The trial consisted of 16 plots where the final crop stocking ranged from 350 stems/ha to 630 stems/ha using a response surface design with uneven plot replication. The stocking of unpruned followers ranged from 0 to 357 stems/ha (Table 8.1). All plot trees were assessed for disease in 1997, 1998, and 1999. The method of Kershaw *et al.* (1988) was followed where the proportion of crown showing symptoms of *Cyclaneusma* to uninfected green crown was estimated and given as a percentage. Needle loss due to suppression or previous years' infection was ignored. Treatment differences were tested by performing stepwise regressions and undertaking analyses using generalised linear models (McCullagh & Nelder 1989).

Results and discussion

Disease levels of the final-crop trees were significantly lower than the followers in 1997 ($p<0.0001$) and in 1998 ($p<0.025$). In 1997, final-crop trees had an average disease level of 2.9%

TABLE 8.1 – Treatments for the Kaingaroa followers trial

No. of plots	3	1	2	7	2	1
Total stocking (stems/ha)	350	410	410	500	590	630
Final crop stocking (stems/ha)	350	307	270	270	270	273
Followers stocking (stems/ha)	0	103	140	230	320	357

compared with 11.7% for followers. In the following year disease levels averaged 17.2% and 22.5% for final-crop trees and followers, respectively. In 1999 there was no significant difference between final-crop trees and followers with disease levels averaging 14.7% and 15.7% respectively.

Total stocking had no effect on disease. Average disease levels were 9.1% for plots stocked at 350 stems/ha with no followers and 17.2% for the one plot stocked at 630 stems/ha (including 357 stems/ha followers), but the average disease level over 3 years for the three plots stocked at 590 stems/ha was 12.8% (Table 8.2). Beets *et al.* (1997) found significantly lower *C. minus* symptoms (assessed as needle retention) at age 22 in plots stocked at 550 stems/ha than at 60 stems/ha or 180 stems/ha.

The finding that pruning and reducing crop density had only a minor effect on disease severity was not unexpected. The removal of infected lower branches provides a measure of control of those foliar pathogens which sporulate only on living leaves and not on leaves lying on the forest floor. *Dothistroma pini* is a good example of such a pathogen (Gadgil 1970). *Cyclaneusma minus* fruits prolifically on needles in the litter layer and therefore cannot be controlled by pruning.

Dense stands provide favourable conditions for the spread of and infection by pathogens which depend on rain splash for spore dispersal and those which require long leaf-wetness periods for infection. Opening up a stand increases the distance between neighbouring trees and reduces the effectiveness of splash-dispersed spores which can travel only short distances. It also reduces the length of leaf-wetness periods by promoting air circulation. *Cyclaneusma minus* ascospores are forcibly ejected from the apothecia and are dispersed by wind; the fungus also does not require long periods of leaf wetness for infection. Reducing the stocking therefore has little effect on either spore dispersal or infection by *C. minus*.

TABLE 8.2 – Mean disease levels from 1997 to 1999 for final-crop trees and followers at various stockings

Stems/ha	Assessment year	Disease level (%)		
		Final-crop	Followers	Total
350	1997	2.7		2.7
	1998	14.8		14.8
	1999	9.8		9.8
410	1997	2.6	13.6	4.1
	1998	18.4	20.3	18.7
	1999	17.1	17.1	17.1
500	1997	3.4	11.8	6.0
	1998	17.1	21.3	18.5
	1999	16.1	16.9	16.3
590	1997	1.6	7.9	4.2
	1998	16.8	19.0	17.7
	1999	15.8	17.6	16.5
630	1997	3.7	15.6	9.0
	1998	22.0	40.2	30.1
	1999	12.1	12.9	12.4
Mean	1997	2.9	11.5	5.2
	1998	17.2	23.2	18.8
	1999	15.0	16.4	15.4

The difference in disease levels of the final-crop trees and followers, while statistically significant, were small in practical terms. If one examines the proportion of trees within each treatment exhibiting disease levels of 50% or more (i.e., trees that would be subject to significant growth loss), between-treatment differences are small (Table 8.3).

In 1997 and 1998 followers had a higher proportion of trees in the 50% or over disease class; in 1999 the final-crop trees had a higher proportion of trees in the high disease class. The higher disease levels recorded for unpruned trees than for the pruned trees are primarily an artefact of the assessment method. The deeper crowns of unpruned trees have a higher proportion of diseased foliage to green foliage because symptoms of Cyclaneusma needle-cast develop mainly in the middle and lower crown. Pruning lowers the assessed disease level because of the removal of the infected lower foliage from view.

8.3 EFFECT OF SELECTIVE THINNING

Introduction

Surveys have shown that, in disease-prone regions, trees susceptible to Cyclaneusma needle-cast are usually distributed randomly in a stand and the incidence of such susceptible trees varies from 20% to 60% (*see* Chapter 4). It has also been shown that the same trees show symptoms of the disease year after year, i.e., the susceptibility of the trees to the fungus remains constant over time (*see* Chapter 5)

although the severity of the symptoms may vary. It should therefore be possible to reduce the incidence of the disease in a stand by selecting and removing disease-prone trees during the first and second thinning operations, provided two conditions are met. Firstly, the initial stocking of the stand must be high enough to allow the removal of up to half the total. Secondly, the first thinning must be delayed until age 7 or 8 as the symptoms of the disease cannot be positively identified before the trees are at least 6 years old.

The results of a trial, designed to test the effectiveness of thinning at different ages, using susceptibility to Cyclaneusma needle-cast as the principal criterion for tree selection, are reported below.

Methods

In 1985, plots were established at two sites (Cpt 35 and 482) in Kaingaroa Forest. Compartment 35 is located at Waiotapu and was planted in 1981 at 1250 stems/ha. Compartment 482 is located in southern Kaingaroa near the Awatea airstrip and was planted in 1980 at 1667 stems/ha. In each compartment, 13 plots of 0.1 ha with 20-m surrounds were randomly laid out and treatments were assigned randomly. Thinning effects were investigated by applying five different thinning ratios at various stand ages (Table 8.4) using a response surface design (Goulding & Inglis 1990).

The first pruning lift to 2.2 m took place at a mean crop height of 4.5 m. The second lift to 4.2 m

TABLE 8.3 – **Proportion of trees in each treatment with disease levels assessed at 50% or greater.**

| Year | Trees assessed with disease levels 50% or greater (percentage of total) | |
	Final-crop	Followers
1997	0.5	1.0
1998	7.3	9.0
1999	3.4	2.2

TABLE 8.4 – **Number of plots per treatment.**

| Thinning ratio | (Initial/final stems/ha) | Stand age (years)* | | | | |
		4	5	6	7	8
1.3	(325/250)			1		
1.6	(400/250)		1		1	
2.4	(600/250)	1		5		1
3.2	(800/250)		1		1	
3.5	(875/250)			1		

* Cpt 482 was planted 1 year earlier than Cpt 35 — therefore thinning started at age 5.

occurred at a mean crop height of 7.5 m. All plot trees were pruned, to eliminate confounding the pruning and thinning effects and so as not to influence future thinning selection. The selection for thinning was based on disease severity, where the most severely diseased trees were removed. Other criteria such as stem form, tree size, and spacing were considered when disease levels were uniformly low in neighbouring trees. During November 1991 all plots were thinned to the final-crop stocking of 250 stems/ha, again using disease susceptibility as the primary selection criterion.

The efficiency with which disease-susceptible trees could be selected was low when the first thinning took place at ages 4 and 5, as the disease symptoms were scarcely visible at this early age. At age 6, selection was easier and the selection efficiency was considered to be medium. At ages 7 and 8, susceptible trees could be detected with ease and a high efficiency of selection could be achieved.

Disease levels were assessed immediately prior to thinning in October/November and every year thereafter, when disease symptoms were visible, using the 5% step method for the assessment of Dothistroma needle-blight (Kershaw *et al.* 1988). The dbh of plot trees were measured at the same time.

Treatment responses were tested using a stepwise multiple regression where the response variates were disease level, dbh, and current year's increment. The independent variables (regressors) were disease levels of the penultimate and current year, thinning ratio (TR), thinning age (TA),

thinning ratio multiplied by thinning age (TR×TA), thinning ratio squared (TR^2), and thinning age squared (TA^2).

To examine the effects of silviculture since the first thinning was carried out, relationships between the independent silvicultural variables and disease levels, dbh, and increment were tested.

Results

In Tables 8.5 and 8.6 are given plot means for dbh in 1991 (prior to the final thinning); increment 1990–91; average disease levels for 1990–91, 1992–96, and 1989–98; dbh in 1999, and increment from 1989 to 1999. Compartment means given are for all 13 plots; thinning treatments 600/250 at age 6 for Cpt 35 and at age 7 for Cpt 482 are means of five plots.

Effect of the first thinning

In Tables 8.7 and 8.8 are shown the results of stepwise regression analysis for Cpt 35 and Cpt 482 data on average disease level over 2 years between the last first thinning in 1989 and the second thinning in 1991, dbh in 1991, and diameter increment from 1990 to 1991.

At Cpt 35, thinning ratio and thinning age had a significant effect on disease level where a delayed heavy first thinning resulted in significantly lower disease levels (Table 8.7). Thinning age had no effect on dbh or increment, but the plots with a heavy first thinning had higher dbh and increment than those subjected to a light first thinning.

TABLE 8.5 – Assessment results for Cpt 35

Stocking	Thinning age	After first thin (stems/ha varies)			After second thin (250 stems/ha)			Increment 1989–99 (mm)
		Dbh 1991 (mm)	Increment 1990–91 (mm)	Disease 1990–91 (%)	Disease 1992–96 (%)	Disease 1989–98 (%)	Dbh 1999 (mm)	
600/250	4	265.7	20.7	41.7	24.5	20.5	460.4	222.7
400/250	5	254.6	23.1	40.7	25.3	22.5	428.6	220.4
800/250	5	207.0	16.7	37.4	26.4	19.0	412.6	222.3
325/250	6	252.1	26.4	28.0	23.2	18.0	448.1	240.1
600/250*	6	221.9	18.5	34.7	20.2	16.3	408.8	213.4
875/250	6	201.4	15.4	40.7	20.6	16.4	420.3	236.5
400/250	7	263.0	28.6	15.4	7.4	7.8	461.4	240.1
800/250	7	240.3	20.8	31.4	12.5	11.3	445.7	239.8
600/250	8	247.1	21.1	24.6	12.5	11.4	450.8	232.6
Cpt mean		235.5	20.6	32.8	19.2	16.0	428.6	224.7

* Mean of five plots

TABLE 8.6 – Assessment results for Cpt 482

Stocking	Thinning age	After first thin (stems/ha varies)			After second thin (250 stems/ha)			Increment 1989–99 (mm)
		Dbh 1991 (mm)	Increment 1990–91 (mm)	Disease 1990–91 (%)	Disease 1992–96 (%)	Disease 1989–98 (%)	Dbh 1999 (mm)	
600/250	5	220.0	23.4	21.6	11.6	9.3	394.4	211.8
400/250	6	235.2	29.7	9.6	9.1	8.6	402.4	211.9
800/250	6	209.3	24.0	30.0	18.5	13.4	376.0	200.5
325/250	7	212.8	25.5	7.0	6.5	5.5	366.4	195.8
600/250*	7	212.8	23.9	20.0	13.9	10.1	387.7	211.2
875/250	7	205.5	23.5	17.3	8.8	5.6	393.4	223.0
400/250	8	221.8	27.1	13.4	13.4	13.6	411.0	230.3
800/250	8	204.0	21.1	21.3	14.4	10.4	399.6	226.9
600/250	9	199.6	21.1	12.9	12.2	10.5	403.1	235.9
Cpt mean		213.4	24.4	17.0	12.0	9.8	391.1	214.8

* Mean of five plots

TABLE 8.7 – Stepwise regression analysis for disease level, dbh, and dbh increment at Cpt 35.

Response variate	Regressor	Estimate	Prob>F	R^2
Average disease level 1990–91	Intercept	158.9	0.002	0.85
	TR	−36.7	0.036	
	TA	−19.7	0.004	
	TR×TA	5.9	0.021	
Dbh 1991	Intercept	264.2	0.000	0.39
	TR^2	−4.7	0.022	
Increment 1990–91	Intercept	31.9	0.000	0.60
	TR	−4.7	0.002	

TABLE 8.8 – Stepwise regression analysis for disease level, dbh, and dbh increment at Cpt 482.

Response variate	Regressor	Estimate	Prob>F	R^2
Average disease level 1990–91	Intercept	1.5	0.800	0.43
	TR	6.8	0.014	
Dbh 1991	Intercept	236.5	0.000	0.57
	TR×TA	−1.4	0.003	
Increment 1990-91	Intercept	30.0	0.000	0.58
	TR×TA	−0.3	0.003	

At Cpt 482, thinning ratio had a significant effect on disease level where a heavy first thinning resulted in significantly lower disease levels (Table 8.8). Thinning age had no effect on disease level at this site. The interaction of thinning age and thinning ratio had an effect on dbh and increment; the plots with a heavy first thinning had greater dbh and increment than those subjected to a light first thinning. Disease incidence and severity after the first and second thinning operations are shown in Table 8.9. The early first thinning did not reduce the percentage of susceptible trees in the stand, and 48% of the remaining trees had disease levels averaging over 40%. In contrast, the late first thinning reduced the incidence of susceptible trees to about 20%, the incidence ranging from 10% after a heavy late thinning to 33% after a light first thinning.

TABLE 8.9 – Disease incidence and severity by treatment at Cpt 35 (incidence defined as the percentage of trees with a mean disease severity of over 40% for each of the two periods)

Treatment	Stocking		Period	Disease incidence (%)	Disease severity (%)
Early thinning	400/250	After first thinning	1990–91	48	64
		After second thinning	1992–96	17	59
	600/250	After first thinning	1990–91	48	66
		After second thinning	1992–96	24	51
	800/250	After first thinning	1990–91	48	62
		After second thinning	1992–96	25	47
Late thinning	400/250	After first thinning	1990–91	10	49
		After second thinning	1992–96	0	-
	600/250	After first thinning	1990–91	18	66
		After second thinning	1992–96	4	49
	800/250	After first thinning	1990–91	33	62
		After second thinning	1992–96	4	50

Effect of the second thinning

After the second thinning, disease incidence averaged 22% in the plots with an early first thinning compared with 3% for the late thinned plots. In 1999 at the end of the experiment, no treatment effects could be demonstrated for dbh or dbh increment at Cpt 35 or Cpt 482. However, thinning age had a highly significant effect on average disease level from 1989 to 1998 at Cpt 35 ($p>0.006$). The plots thinned at ages 4 and 5 had mean disease levels during the period from 1989 to 1999 of 21%, compared with 10% for the plots thinned at ages 7 and 8. The early-thinned plots had lower dbh (433.9 mm) than the late-thinned plots (452.6 mm). Increments (1989–99) were 221.8 mm and 237.5 mm respectively, a difference of 15.7 mm (Fig. 8.1).

Individual trees from early- and late-thinned plots were classified into two groups that had mean disease levels, from 1 to 30% and 31 to 80%, taken over the period 1989 to 1999. Differences in disease incidence, dbh, and increment were apparent (Table 8.10).

In Cpt 35, disease severity exceeded 30% in 28% of the trees in plots thinned at ages 4 and 5,
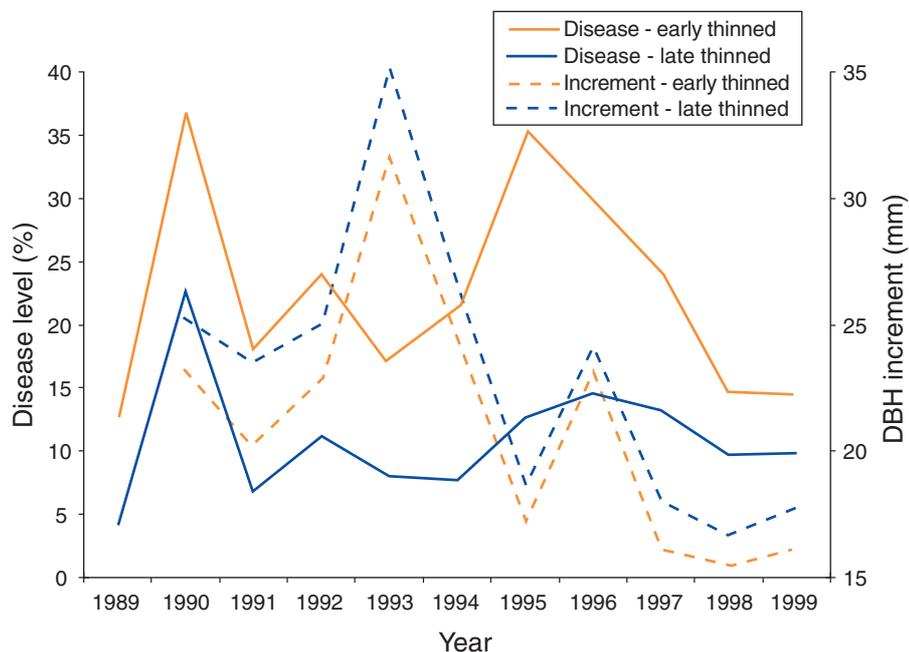

FIG. 8.1 – Disease levels and increments for the early- and late-thinned plots at Cpt 35

TABLE 8.10 – Dbh, disease, and increment of disease classes by treatment at Cpt 35

Treatment and disease class	Number of trees	Dbh 1999 (mm)	Disease level 1989–98 (%)	Increment 1989–99 (mm)
Early thinned stands (1–30%)	52	453.5	13.7	235.9
Early thinned stands (31–80%)	20	384.5	38.8	185.3
Late thinned stands (1–30%)	65	455.2	9.3	239.6
Late thinned stands (31–80%)	2	359.0	41.1	166.5

compared with 3% of the trees in the plots thinned at 7 and 8 years of age. These figures demonstrate that it is possible to select susceptible trees during thinning and that the selection can be successful in markedly reducing disease incidence. For the early-thinned stands, there was a 21% reduction in diameter increment for trees in the 31–80% disease class compared with the trees in the 1–30% disease class. There was a difference in mean disease levels of 25%, which conforms with the disease-severity/growth-loss relationship described in Chapter 5. For the trees in the 1–30% disease level class, there was no difference in diameter between early- and late-thinned plots.

Compartment 482 had consistently lower disease incidence and severity than Cpt 35 over the duration of the trial. The final selection thinning removed nearly all the severely affected trees, which reduced disease to very low levels. The effect of thinning age and thinning ratio on dbh, which was apparent after the first thinning, disappeared, and no difference between the late-thinned plots and the early-thinned plots could be demonstrated at this site.

8.4 DISCUSSION

These results show that Cyclaneusma needle-cast can be effectively controlled by delaying the first thinning to age 7 or 8 and using susceptibility to the needle-cast as a primary selection criterion. By controlling the disease in this way, growth losses attributable to the needle-cast, which could be as much as 55–70 m^3/ha in areas where the disease severity is high, can be almost eliminated. Even in areas where the disease severity (and therefore the growth loss) are generally low, there was no difference in diameter between plots which were thinned early and those that were thinned late, showing that delaying the thinning was not disadvantageous in terms of growth.

There is one caveat that needs to be borne in mind in considering these results. It is possible that delaying the thinning and pruning operations might lead to the branch stub size being unacceptably large. This possibility was not explored in this trial as all plot trees were pruned at age 4 or 5 years to ensure that the selection of trees in the late thinning was not biased. If branch stub size is a problem, then all trees in a stand will have to be pruned early. The extra cost of pruning trees that are later thinned to waste was not quantified in this study. If this extra cost makes delayed late thinning economically unattractive, a routine thinning and pruning operation at age 4 or 5, followed by a later second thinning in which susceptibility to Cyclaneusma needle-cast is the principal selection criterion, might be undertaken. Although not as effective as a delayed thinning, this procedure would reduce the number of susceptible trees in a stand. In this trial, it was possible to identify and select for removal disease-susceptible trees in all treatments during the second thinning in 1991. However, almost 50% the trees in the early-thinned plots were categorised as disease-susceptible after the first thinning. Therefore, after allowing for spacing and tree form constraints, it was not possible to remove all susceptible trees during the second thinning and over 20% of the final crop trees were disease-susceptible. In the late-thinned plots, the first thinning removed a significant proportion of disease-susceptible trees, thereby allowing the opportunity to remove almost all of the disease-susceptible trees during the second thinning and maintain spacing and form standards.

There is a policy in some regions to plant at 500 stems/ha and leave all trees to end of rotation. This regime provides no opportunity to thin susceptible trees. While the stocking *per se* will have little effect on stand disease level, on disease-prone sites a substantial proportion of the trees in the stand will be subjected to high levels of needle cast and

subsequent growth loss. In these situations it is likely that a traditional regime of planting more trees (800–900 stems/ha) and carrying out a thinning at age 7 to remove susceptible trees will be economically beneficial.

Northland, Auckland, Waikato, Bay of Plenty, Taupo, Gisborne, Westland, and Otago, as well as microsites, particularly high-altitude sites, in other regions have been identified as high risk areas in which high incidence and severity of Cyclaneusma needle-cast may be expected (*see* Chapter 4). Work described in this chapter has shown that, for these areas, the ideal silvicultural regime for the control of Cyclaneusma needle-cast is a heavy delayed first thinning (e.g., from 1250 stems/ha to 400–500 stems/ha at age 7) followed by a second thinning at age 9 or 10 to remove the remaining disease-susceptible trees.

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APPENDIX 1

NEW ZEALAND BIOLOGICAL REGIONS

Code	Biological region
AK	Auckland
BP	Bay of Plenty
BR	Buller
CL	Coromandel
CO	Central Otago
DN	Dunedin
FD	Fiordland
GB	Gisborne
HB	Hawke's Bay
KA	Kaikoura
MB	Marlborough
MC	Mid Canterbury
MK	Mackenzie
NC	North Canterbury
ND	Northland
NN	Nelson
OL	Otago Lakes
RI	Rangitikei
SC	South Canterbury
SD	Sounds (Marlborough)
SI	Stewart Island
SL	Southland
TK	Taranaki
TO	Taupo
WA	Wairarapa
WD	Westland
WI	Wanganui
WN	Wellington
WO	Waikato

APPENDIX 2

LOCATIONS OF COLLECTION SITES

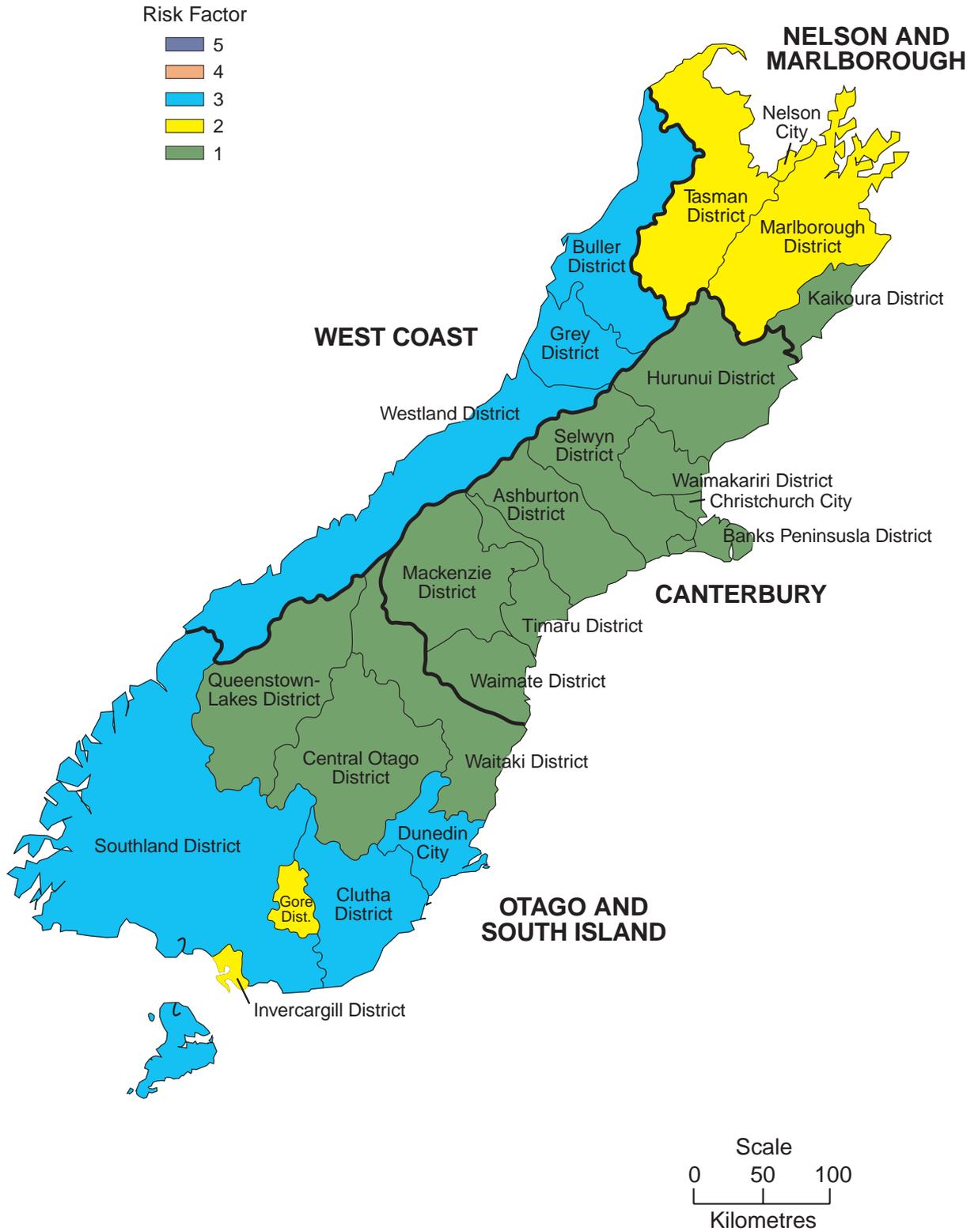| Collection period	Location	Bioregion	Latitude	Longitude
1996–97	Ahipara	Northland (ND)	35°10′	173°09′
1996–97	Pouto Forest	Northland	36°20′	174°06′
1996–97	Mamaranui Forest	Northland	35°50′	173°30′
1997–98	Mamaranui Forest	Northland	35°50′	173°30′
1997–98	Rakautao	Northland	35°27′	173°53′
1998–99	Awakino	Northland	35°46′	173°44′
1998–99	Awakino	Northland	35°46′	173°46′
1998–99	Pipiwai	Northland	35°37′	173°56′
1998–99	Tarawhiti	Northland	35°42′	173°46′
1998–99	Tarawhiti	Northland	35°43′	173°43′
1998–99	Tomarata	Northland	36°13′	174°36′
1996–97	Mahurangi Forest	Auckland (AK)	36°19′	174°35′
1996–97	Albany	Auckland	36°44′	174°41′
1997–98	Woodhill Forest	Auckland	36°45′	174°24′
1998–99	Mahurangi Forest	Auckland	36°19′	174°35′
1998–99	Mahurangi Forest	Auckland	36°21′	174°34′
1998–99	Whenuapai	Auckland	36°47′	174°37′
1998–99	Weiti	Auckland	36°40′	174°38′
1997–98	Onewhero	Waikato (WO)	37°20′	174°55′
1998–99	Onewhero	Waikato	37°20′	174°55′
1998–99	Onewhero	Waikato	37°20′	174°55′
1998–99	Onewhero	Waikato	37°20′	174°55′
1998–99	Onewhero	Waikato	37°20′	174°55′
1998–99	Onewhero	Waikato	37°20′	174°55′
1998–99	Pangani	Waikato	37°15′	175°17′
1998–99	Whangapoua	Coromandel (CL)	36°43′	175°34′
1998–99	Whangapoua	Coromandel	36°34′	175°34′
1998–99	Tairua	Coromandel	37°04′	175°51′
1998–99	Opito Bay	Coromandel	36°44′	175°48′
1996–97	Tikitere	Bay of Plenty (BP)	38°03′	176°21′
1998–99	Tikitere	Bay of Plenty	38°03′	176°21′
1998–99	Tikitere	Bay of Plenty	38°03′	176°24′
1998–99	Omaio Forest	Bay of Plenty	37°50′	177°40′
1998–99	Endean Forest	Bay of Plenty	38°07′	176°35′
1998–99	Tarawera Forest	Bay of Plenty	38°08′	176°35′
1998–99	Waikite	Bay of Plenty	38°20′	176°04′
1997–98	Ruatoria	Gisborne (GB)	37°51′	178°05′
1998–99	Wharerata	Gisborne	38°59′	177°51′
1996–97	Kinleith Forest	Taupo (TO)	38°12′	175°59′
1996–97	Kinleith Forest	Taupo	38°12′	175°59′
1996–97	Kinleith Forest	Taupo	38°15′	175°56′
1998–99	Kinleith Forest	Taupo	38°18′	176°00′
1998–99	Kinleith Forest	Taupo	38°15′	175°57′
1998–99	Kinleith Forest	Taupo	38°26′	175°58′
1998–99	Kinleith Forest	Taupo	38°17′	175°51′
1998–99	Kinleith Forest	Taupo	38°16′	175°52′
1998–99	Kinleith Forest	Taupo	38°18′	175°50′
1998-99	Kinleith Forest	Taupo	38°17′	175°51′
1998-99	Kinleith Forest	Taupo	-	-

Collection period Longitude	Location	Bioregion	Latitude	
1998–99	Kinleith Forest	Taupo	38°14′	176°04′
1998–99	Kinleith Forest	Taupo	38°15′	176°03′
1997–98	Kaingaroa	Taupo	38°44′	176°18′
1997–98	Kaingaroa	Taupo	38°22′	176°26′
1998–99	Kaingaroa	Taupo	38°27′	176°25′
1998–99	Kaingaroa	Taupo	38°42′	176°25′
1997–98	Tauhara	Taupo	38°38′	176°14′
1998–99	Tahorakuri	Taupo	38°35′	176°09′
1998–99	Tahorakuri	Taupo	38°34′	176°09′
1998–99	Tahorakuri	Taupo	38°32′	176°09′
1998–99	Te Rangoroa	Taupo	38°40′	175°19′
1998–99	Lake Taupo Forest	Taupo	38°58′	175°57′
1998–99	Horokino	Taupo	38°26′	175°29′
1998–99	Horokino	Taupo	38°26′	175°29′
1998–99	Lake Mangamahoe	Taranaki (TK)	39°07′	174°07′
1998–99	Waitui	Taranaki	39°20′	174°15′
1998–99	McIntyres Block	Taranaki	39°20′	174°30′
1997–98	Gwavas Forest	Rangitikei (RI)	39°43′	176°26′
1997–98	Gwavas Forest	Rangitikei	39°43′	176°23′
1998–99	Ngaumu	Wairarapa (WA)	40°55′	176°06′
1998–99	Pinedale	Wairarapa	40°50′	175°56′
1997–98	Puketiro	Wellington (WN)	41°04′	175°01′
1998–99	Puketiro	Wellington	41°04′	175°01′
1997–98	Maungakotukutuku	Wellington	40°57′	175°02′
1998–99	Shannon	Wellington	41°13′	174°53′
1996–97	Motueka Forest	Nelson (NN)	41°00′	172°57′
1998–99	Rai Forest	Nelson	41°10′	173°32′
1998–99	Rai Forest	Nelson	41°13′	173°27′
1998–99	Hoults Valley	Nelson	41°24′	173°01′
1998–99	Pearce Block	Nelson	41°13′	172°47′
1998–99	Pearce Block	Nelson	41°14′	172°47′
1998–99	Dovedale	Nelson	41°22′	172°56′
1998–99	Pretty Bridge	Nelson	41°27′	172°58′
1998–99	Rabbit island	Nelson	41°16′	173°09′
1998–99	Lee Valley	Nelson	41°25′	173°09′
1998–99	Golden Downs Forest	Nelson	41°32′	172°51′
1998–99	Golden Downs Forest	Nelson	41°38′	172°52′
1998–99	D'Urville Island	Sounds (SD)	40°46′	173°57′
1998–99	Kaniere	Westland (WD)	42°47′	171°05′
1998–99	Waimea	Westland	42°40′	171°10′
1998–99	West Dome	Otago Lakes (OL)	45°34′	168°15′
1998–99	Akatore	Dunedin (DN)	46°05′	170°03′
1998–99	Otago Coast Forest	Dunedin	46°04′	170°07′
1998–99	Lawrence	Southland (SL)	45°55′	169°41′
1998–99	Castledowns	Southland	45°50′	168°11′
1998–99	Castledowns	Southland	45°49′	168°12′
1998–99	Tangatura	Southland	45°58′	168°14′
1998–99	Dipton	Southland	45°56′	168°23′
1998–99	Rankleburn Forest	Southland	46°03′	169°17′
1998–99	Te Anau	Fiordland (FD)	45°36′	167°55′

APPENDIX 3

TERRITORIAL AUTHORITY BOUNDARIES AND CYCLANEUSMA HAZARD RATINGS
NORTH ISLAND

NORTHLAND

Far North District

Whangarei District

Kaipara District

Auckland City

Rodney District

North Shore City

AUCKLAND

Waitakere City

Manukau City

Papakura District

Franklin District

Matamata - Piako District

Waikato District

Hamilton City

Otorohanga District

CENTRAL NORTH ISLAND

Thames - Coromandel District

Hauraki District

Tauranga District

Western Bay of Plenty Dist.

Kawerau District

Opotiki Dist.

Waipa Dist.

Sth Waikato Dist.

Rotorua Dist.

Whakatane District

Gisborne District

EAST COAST

Waitomo District

Ruapehu District

Taupo Dist.

Wairoa District

New Plymouth District

Stratford District

Hastings District

Napier City

South Taranaki District

Rangitikei District

HAWKE'S BAY

Wanganui District

Manawatu Dist.

Central Hawkes Bay District

SOUTHERN NORTH ISLAND

Palmerston North City

Horowhenua District

Tararua District

Kapiti Coast District

Upper Hutt City

Poirirua City

Masterton District

Wellington City

Carterton District

South Wairarapa District

Lower Hutt City

Risk Factor

5

4

3

2

1

Scale

0   50   100

Kilometres

TERRITORIAL AUTHORITY BOUNDARIES AND CYCLANEUSMA HAZARD RATINGS SOUTH ISLAND

Risk Factor
- 5
- 4
- 3
- 2
- 1

NELSON AND MARLBOROUGH

Nelson City

Tasman District

Marlborough District

Kaikoura District

WEST COAST

Buller District

Grey District

Hurunui District

Westland District

Selwyn District

Waimakariri District

Christchurch City

Ashburton District

Banks Peninsusla District

CANTERBURY

Mackenzie District

Timaru District

Waimate District

Queenstown-Lakes District

Waitaki District

Central Otago District

Southland District

Dunedin City

OTAGO AND SOUTH ISLAND

Gore Dist.

Clutha District

Invercargill District

Scale

0   50   100

Kilometres

GLOSSARY

Abscission layer	A layer of cells, the breakdown of which separates a plant part, such as leaf, fruit or flower, from the plant.
Apothecium (pl. apothecia)	A cup- or saucer-like structure, composed of fungal tissue, containing asci (q.v.), in which the layer bearing the asci is exposed on maturity.
Ascomycetes	The common term for the Ascomycota (q.v.).
Ascomycota	The largest group of the Fungi, for which possession of the ascus (q.v.) is the diagnostic character.
Ascospore	A spore produced in an ascus (q.v.).
Ascus (pl. asci)	The typical sack-like cell, characteristic of the Ascomycota (q.v.), in which takes place firstly nuclear fusion, then nuclear division, and finally the production of the nuclei (generally eight) around which ascospores are formed.
Bacilliform	Rod-like in shape.
Basal area	The sum of sectional areas of all living stems at breast height, expressed in square metres.
Biological regions	In New Zealand, the more or less equal-sized regions, with their boundaries defined by mountain ranges or major rivers when possible, which are broadly based on the climatic regions formerly used by the New Zealand Meteorological Service for weather forecasts.
Chlorotic	Deficient in chlorophyll and, hence, yellowish in colour, generally as a result of disease or nutrient deficiency.
Clone	A group or collection of genetically identical individuals, propagated by asexual means, for example, by cuttings. **–al:** belonging to a clone.
Colony	An artificially grown fungal culture, in the context of this Bulletin.
Compensation (of growth)	In densely stocked stands where space limits growth, the death of a number of trees may allow the remaining trees to grow larger they otherwise would have, thus compensating, to some extent, for the volume lost through mortality.
Diameter at breast height (dbh)	Diameter, usually over bark, measured at 1.4 m above ground on the uphill side of the tree.
Diameter over stubs (DOS)	The horizontal measurement over pruned branch stubs on any pruning lift, always measured over the largest whorl removed in that lift.
Disease incidence	Percentage of the stand area occupied by trees showing symptoms of a disease.
Disease intensity	A description of the prevalence of a disease, where incidence and severity are multiplied to give an overall measure of the frequency and severity of a pest or disease.
Disease severity	Percentage of tree crowns showing symptoms of a disease, averaged over all trees in a stand.
Endophyte	An organism that lives within the tissues of a plant, without producing any symptoms of disease. It may be a latent pathogen (q.v.) that causes disease only under specific environmental conditions or a saprophyte (q.v.) that never causes disease. **–ic**: living as an endophyte.
Filiform	Long and thin, thread-like in form.
Followers	Trees that have not received the same degree of pruning as the "crop" element in a stand and are usually destined for removal prior to clearfelling at stand maturity.
Fruiting body	A structure containing spores.
Genotype	The sum of the generic potential of an organism, genetic constitution.
Infection	Entry and establishment of a pathogenic (q.v.) relationship with an organism.

Infection period	The time over which suitable conditions prevail for infection to occur.
Inoculum	The infective propagules (e.g., spores) of a pathogen (q.v.).
Isozyme	One of a family of enzymes with different molecular weights and electron charges and so separating in electrophoresis.
Morphological	Pertaining to outward form and structure.
Mycelium (pl. mycelia)	A mass of hyphae or fungal filaments.
Parasite	An organism, living on or in, and obtaining its nutrition from, its host, another living organism.
Pathogen	A parasite able to cause disease in a particular host or range of hosts. **–ic**: disease-causing. **–icity**: the condition of being pathogenic.
Phytotoxic	Poisonous to plants, causing injury.
Provenance	Coming from a particular source. In forestry, the term is applied to groups of individual trees of one species which share a common geographical origin, usually a small defined area.
Pycnidium (pl. pycnidia)	A more or less flask-shaped structure, composed of fungal tissue, with a circular or longitudinal opening, the inner surface of which is lined with cells bearing asexual spores.
Pycnidiospore	An asexual spore borne in a pycnidium.
Saprophyte	An organism using dead organic material as its food source.
Sepate	Possessing septa, i.e., partitions or cross walls.
Sporulating	Producing spores.
Stem analysis	A technique used to determine the volume growth of the stem over time. The stem is cut into sections at each mid-internode and for each section the diameter of each growth ring at one or more radii is measured.
Stumpage	A pricing system where the price point is the standing tree. Also, the value of standing timber, when all harvesting costs have been paid. Stumpage (usually expressed as $/m^3) is the revenue at harvest. It takes no account of the growing costs of wood.

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