ARTICLES

Mortality trends in *Pinus radiata* in the Rotorua region

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ABSTRACT

Over the 10- to 20-year age range, ***Pinus radiata*** *stands established in the 1960s show mortality rates substantially below those established between 1945-55 and 1939-42. A reappraisal of the economics of thinning is recommended, and users of growth models are warned to expect overprediction of mortality.*

INTRODUCTION

The incidence of mortality in *Pinus radiata* stands is well known, although not particularly well documented.

Spurr (1962) studied growth and mortality in 1925 plantings in Kinleith Forest. His data, although having a gap of five years from age 13-17 inclusive, show a fairly steady pattern of annual mortality up to age 20. Although providing no information on cause of death, his study suggested that trees destined to die could be identified by their decline in basal area increment some years before death, and he recommended they be removed to improve stand health.

Jackson (1955), in a study of stand development and heavy mortality in 1937-1944 plantings in Rotoehu Forest, attributed most of the mortality to *Sirex* attack. He concluded that *Sirex* established itself in the suppressed element of the stand during the sixth and seventh years, spreading to some of the healthy dominants during the eighth and ninth years, then beginning to tail off from peak annual levels of 10-15%. He regarded an unthinned stand which had reached the age of 12 years without progressive attack as being in an explosive state and advocated prior thinning of suppressed trees as a preventative measure.

However, since the above studies were made, there have been considerable advances in the control of *Sirex* and of diseases such as *Dothistroma pini.*

Thinning regimes for *Pinus radiata* are increasingly being assessed with the aid of predictive models such as growth and yield models. Thus it is important that growth models present a true picture of current rates of mortality, but herein lies a problem. If it is to have any degree of accuracy, a growth model must be based on actual data. In order to project the growth of a stand being planted now, the growth model must interpret data which have been collected over the previous 25-30 years. However, in doing so, it is not allowing for any change in mortality patterns as a result of improvements in seed stock, tending practices, pest control, etc., in the intervening period.

Empirical observations suggest that rates of mortality have decreased in recent years. If this is true, allowances need to be made in assessing the yields and also the economics of thinning, especially for pulpwood regimes. Consequently, an analysis of existing data was undertaken to determine whether there has been any significant decrease in mortality rates in highly stocked stands in the Rotorua region.

THE DATA BASE

A search was made for suitable permanent sample plot data from Kaingaroa, Whakarewarewa, Tarawera, and Rotoehu plantations of radiata pine. Plots with mortality recorded over the age range 10-20 years were selected from stands that were unthinned (or thinned only once before age 10) and stocked at more than 700 stems/ha.

For the analysis, the available plots were divided into three groups by establishment year:

Group 1: Established 1939-1942
Group 2: Established 1945-1955
Group 3: Established 1960-1964

No 'old crop' data from earlier plantings were available in the required age range from these forests.

In spite of the apparently large volume of permanent sample plot data available, only 14 plots fitted the criteria for Group 1, 17 for Group 2, and 45 for Group 3. As the samples were too small to subdivide into different soil types, site indexes, etc., such variables had to be ignored in the analysis. The sizes of the samples also meant that, although it was perfectly feasible to make comparisons between them, the development of a model to predict mortality was not possible.

Details of individual plots are available from the author.

ANALYSIS

From the plot data the mean annual mortality was calculated as a percentage of initial stocking:

$$M = \frac{100\,(N - N^1)}{(t^1 - t)\,N}$$

where N = stocking (stems/ha) as close to age 10 as recorded.
N^1 = stocking (stems/ha) as close to age 20 as recorded.
$t^1 - t$ = number of years between N and N^1.

Regressions were tested for $\bar{M}$ against N, $\sqrt{N}$, and $\ln(N)$ separately and in combination. The relationship $M = b\sqrt{N} + a$ gave the most consistent fit. Fig. 1 illustrates the data points and the resulting regression curves with equations as follows:

Group 1 (1939-1942 plantings)

$$M = 0.086\sqrt{N} + 1.415 \qquad (r^2 = 0.807;\ S_{\bar{M}} = 0.55)$$

Group 2 (1945-1955 plantings)

$$M = 0.143\sqrt{N} - 2.876 \qquad (r^2 = 0.869;\ S_{\bar{M}} = 0.55)$$

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Group 3 (1960-1964 plantings)

$$M = 0.146\sqrt{N} - 3.441 \qquad (r^2 = 0.873;\ S_{\overline{M}} = 0.58)$$

Two covariance analyses were carried out: one compared the three groups of data and the other compared Groups 2 and 3 only.

DISCUSSION

The covariance analysis that compared the regression curves for the three groups showed a highly significant difference between them. The analysis that compared Groups 2 and 3 only also revealed a significant difference, confirming that mortality has decreased in the forests studied.

To illustrate the results, Table 1 shows examples of the mortality over the 10-year period, converted to survivors per hectare at age 20.

TABLE 1 — Expected stocking at age 20

Live stems/ha at age 10	Live stems/ha at age 20 (95% confidence interval)		
	1939-1942 establishment	1945-1955 establishment	1960-1964 establishment
1000	545- 629	813- 867	864- 900
2000	884-1012	1222-1370	1336-1428
3000	1029-1293	1329-1695	1521-1743

Thus, for example, of 1000 stems/ha live at age 10, at age 20 a maximum of 629 stems could be expected to remain in a 1940 planting, whereas a minimum of 864 could be expected from a 1960 planting. It would be reasonable to assume that this absolute minimum of 235 additional stems would represent considerable extra merchantable volume and may also have an impact on piece size. Even though site quality was not taken into account, it is worth observing that at age 20 only one Group 1 plot showed a mean annual increment (MAI) above 30m^3 ha^{-1} but very few Group 2 and 3 plots had MAI's less than 30 and indeed many in Group 3 were above 40m^3 ha^{-1}.

Table 1 indicates a larger decrease in mortality between Groups 1 and 2 than between Groups 2 and 3. This could well be the result of some residual effects of the *Sirex* epidemic on Group 1 plots in the early 1950s.

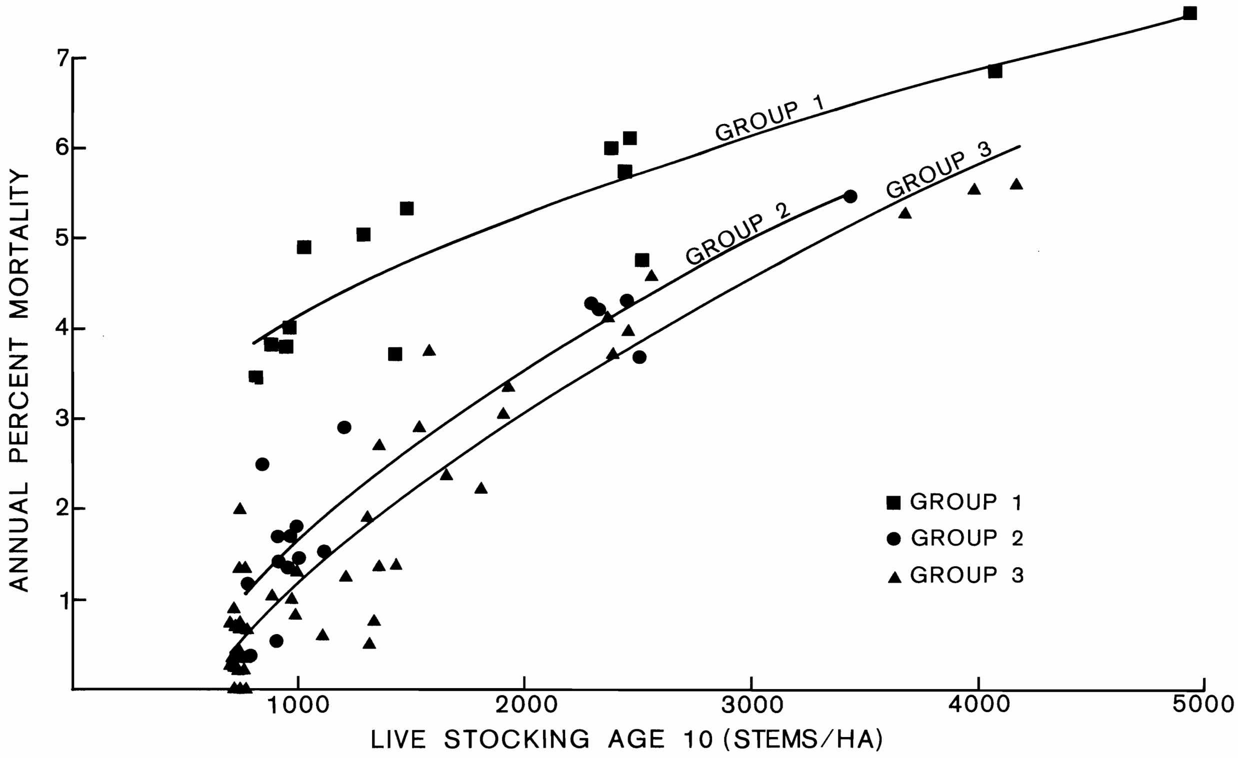
Group 3 was heavily dependent on data from one area of Tarawera Forest (30 out of 45 plots). Was it possible that the lower mortality was peculiar to Tarawera? To investigate this possibility, the group was subdivided into Kaingaroa (the remaining 15 plots) and Tarawera, and individual regressions obtained. A covariance analysis showed no significant difference between the two. Examples of 95% confidence intervals for predicted mean mortality were:

1000 stems/ha: Kaingaroa 0.72-1.38; Tarawera 0.99-1.45
1500 stems/ha: Kaingaroa 1.32-2.36; Tarawera 2.06-2.48

As expected, the Kaingaroa data were more variable than the Tarawera data, but the predicted mortality tended to be lower. Thus it seems reasonable to conclude that the reduction in mortality shown in this study was not confined to any particular area within the region.

There is a noticeable change in the slopes of the mortality curves. Those for Groups 2 and 3 are almost the same, indicating a similar pattern of mortality over the entire range represented. However, a comparison between these and the Group 1 curve suggests that the greatest reduction in mortality percentages has been in the lower stockings of those studied. Although it is not valid to extrapolate beyond the limits of the data used, it is interesting to speculate

FIG. 1–Mortality/live stocking regressions



whether there would be any great difference in mortality figures for the three groups at, say, 5000 stems/ha.

As noted earlier, no suitable old-crop data were found, but some comparisons can be made with the data from 1925 plantings in Kinleith Forest used by Spurr (1962). Although these stands do not exhibit such high mortality as those of Group 1, they do show higher mortality than that projected by the regressions derived from Groups 2 and 3. Spurr's data show a mean live stocking of 1519 stems/ha at age 10 and 985 at age 20. For the same mean stocking at age 10, the regression for Group 2 plots (1945-1955 establishment) indicates a 95% confidence interval for mean stocking at age 20 of 1109 ± 44 stems/ha and for Group 3 plots (1960-1964 establishment) of 1177 ± 27 stems/ha. It could be argued that the lower mortality exhibited by post-1960 plantings in this study could be merely the result of the control of the *Sirex* and *Dothistroma* outbreaks. However, the comparison with Spurr's old-crop data suggests that there must be other factors involved, such as improvements in seed stock and in establishment and management practices.

It would be of considerable interest to be able to extend the age range to 25 or even 30 years, but unfortunately this is not yet possible. Most of the Group 1 data includes measurements up to this age, but the 1945-1955 data consist almost entirely of plots which were abandoned at about age 20. Because many of the Group 3 plots are still current and unthinned, an extension of the range could well be possible in a few years' time.

Beekhuis (1966) used relative spacing to study trends in mortality, where relative spacing (%)

$$= \frac{100 \text{ x triangular spacing}}{\text{predominant mean height}}$$

$$= \frac{107.4 \text{ x square spacing}}{\text{predominant mean height}}$$

His data suggested that *Pinus radiata* could attain a maximum density that corresponded to a minimum relative spacing of 10-12%.

The lack of data in the 20+ age range means that the Beekhuis theory of relative spacing cannot yet be verified or refuted. It is interesting to note, however, that many Group 3 plots, particularly those in high site index areas like Tarawera Forest and the northern boundary area of Kaingaroa Forest, were showing relative spacing considerably below 10% at around age 20.

In his review of 1979 radiata pine management practices, Williams (1982) noted that initial stockings appeared to have decreased significantly since 1970, possibly as a result of improvements in land clearing, nursery growing, forest establishment techniques, and genetic quality of tree stocks. The range was wide, but he noted a mid-range of around 1600 stems/ha for clearwood and structural regimes, and 2220 stems/ha for others. Of the 45 most recently established plots used in this study, six were planted at 1370 stems/ha, a further nine at 2270 stems/ha, and the remainder at 3000 stems/ha or more. Hence, they cannot be said to be truly representative even of 1979 establishment regimes, let alone those of current or future management practice. Trewin (1981) showed that improved handling and planting techniques promoted more even growth within the stand. Any comment regarding the effect of lower initial stockings and more even growth on mortality would be mere speculation, but obviously there is a need to monitor this effect.

A search of the PSP data base for additional plots which would be suitable for subsequent monitoring of mortality trends (provided they continued without thinning) revealed some 32 plots located in stands planted between 1965 and 1974 in the Rotorua region. Most noticeable was a complete absence of data for stockings of 1000-2000 stems/ha at age 10, which is the range to be expected in unthinned stands planted at reduced initial stockings.

CONCLUSIONS AND RECOMMENDATIONS

1. The analysis shows that over the past 30 years there has been a significant reduction in mortality in *Pinus radiata* over the age range 10-20 years in the Rotorua region. Assuming that the lower mortality will mean increased mean annual increments, a fresh evaluation of the economics of thinning is suggested.
2. The results of the analysis indicate that predictive models based on existing data will tend to overestimate mortality. Hence, it is recommended that care should be taken in using growth models to assess future higher stocking regimes.
3. It is recommended that sufficient sample plots be located in highly stocked stands to allow continued monitoring of any changes in mortality. In particular, plots are needed in the Rotorua region in stands carrying stockings of 1000-2000 stems/ha at age 10.

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