THE TENDING OF PINUS RADIATA IN SOUTHLAND

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SYNOPSIS

The objects of management for Pinus radiata (D.Don) in Southland Conservancy are the production of the maximum volume of high quality sawlogs and of veneer logs. To achieve these objects, a silvicultural schedule has been developed to:

(a) maintain as high a rate of volume increment as possible;
(b) maintain deep green crowns, preferably down to the level of the pruned logs;
(c) restrict to five or six inches the diameter of the knotty core in pruned logs.

The schedule, as defined in terms of top height and stems per acre (s.p.a.), is:

<table>
<thead>
<tr>
<th>Top height (ft)</th>
<th>Age (years)</th>
<th>Pruning regime (height and s.p.a.)</th>
<th>Thinning (residual s.p.a.)</th>
<th>Yields (cu.ft p.a.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>5</td>
<td>to 6 ft: 250–300 stems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>7</td>
<td>6–12 ft: 70–100 stems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>8</td>
<td>12–18 ft: 70–100 stems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>10</td>
<td>18–24 ft: 70 stems</td>
<td>250</td>
<td>Minor produce</td>
</tr>
<tr>
<td>45</td>
<td>12</td>
<td>24–32 ft: 70 stems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>15</td>
<td></td>
<td>160</td>
<td>900</td>
</tr>
<tr>
<td>73</td>
<td>19</td>
<td></td>
<td>100</td>
<td>1,100</td>
</tr>
<tr>
<td>95</td>
<td>27</td>
<td></td>
<td>70</td>
<td>1,500</td>
</tr>
<tr>
<td>120</td>
<td>40</td>
<td>Clearfell</td>
<td></td>
<td>9,800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total yield</td>
<td></td>
<td>13,300</td>
</tr>
</tbody>
</table>

The thinning regime, from the second thinning onwards, is hypothetical, and is deduced from the stocking necessary to:

(a) maintain deep green crowns;
(b) provide sufficient growing space to maintain the maximum rate of diameter growth;
(c) fully utilise the overall productive potential of the site.

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INTRODUCTION

No forester who has worked with the exotic pines grown in New Zealand will now have faith in natural pruning as an economic method of producing clear timber. The very low proportion of high grade pine timber cut by our mills originates in the adoption of European methods of maintaining dense stocking to achieve natural pruning. These methods are unsuitable for the species, climate, growth rate and markets here.

The most serious avoidable defects in our exotic timbers are loose bark-encased knots caused by the growth of the bole over dead branches which have failed to prune naturally (Fenton and Hamilton, 1961). This can be corrected by a combination of:

(a) Artificial pruning, carried out as high up the tree as is economically possible, to produce clear timber from the lower logs.

(b) Thinning of a sufficient intensity to keep alive the branches above the pruned level; the branches in the two sawlog lengths above the pruned level preferably being moribund.

Timber sawn from logs above the pruned level will then be less likely to contain bark-encased knots than timber from comparable logs from less heavily thinned; although some degrade caused by the early death of small branches and by stem-cone holes may still occur.

This new concept of silviculture also ensures a high rate of increment on the best trees which should yield the best proportion of high grade timber that is economically feasible on present day costs, grading standards and realisations.

The observations on which this analysis is based were made in exotic forests established in Southland and Otago. The site qualities of these forests are slightly below the average for *P. radiata* in New Zealand (Hinds, 1955). The data have been related to either mean top height, or age; the relationship between these two criteria, as used in this paper, is shown in fig. 1, which represents mean top height development with age for *P. radiata* of Site Index 75 (Lewis, 1954). If it is desired to apply the results to stands with a different rate of growth, then the basis should be the mean top height.

CROWN CHARACTERISTICS AFFECTING TENDING

The Importance of the Level and Depth of the Green Crown

Trees in plantations do not compete with one another until some years after planting. The lower branches become moribund when shade cast by adjacent trees and higher branches reaches a certain intensity; they die when further development of the stand brings about still greater intensity of shade. This appears to be quite critical, as the transition from completely green to dead branches is sudden. In stands planted at a spacing of $8 \times 6$ ft the lowest branches
start to die when the dominant trees are 20 ft high. The level of the dead branches in a stand rises at about the same rate as the height growth of the dominant trees, so as to give an initial depth of green crown of 20 ft. The natural mortality of trees in a stand allows the depth of green crown to increase to about 25 ft when the dominant trees are 75 ft high. If the stands are thinned, however, the crown remains alive to a depth which is related to the new stocking. For example, in a stand thinned to 250 stems per acre at 35 ft top height (10 years) the green crown will develop for a depth of 46 ft by the time that stand top height has reached 60 ft (i.e., 16 years). This is shown more clearly in fig. 2.
Fig. 2. Relationship between stand top height and age showing the stages of pruning required to maintain a core of entirely intergrown knots, and the effect of thinning on green crown development.
A variation from this pattern occurs where trees grow in competition with weeds from an early age. Long grass can cause the death of lower branches in the second year from planting, but broom and gorse can continue to cause premature death of branches for a number of years. It is also likely that exceptional weather conditions, particularly drought, can influence the depth of the green crown.

While branches are green, the cambium of the branch is continuous with that of the stem; as the stem increases in diameter, it must grow over the branches. The bark of the branch is sloughed off onto the stem, and forms the familiar concentric corrugations of bark encircling the branch at its junction with the stem. The stem wood consequently intergrows with that of the branch. When the branch dies, its cambium dries out, and the bark can no longer slide onto the stem. The stem in its growth will then encompass the branch and its dead bark. The loose bark-encased knots in the timber sawn from the subsequent growth are the major cause of degrade.

There is an extensive literature on the effects of green pruning on increment, and a recent paper by Moller (1960) reviews 22 papers on this subject; Hawley (1954) mentions further references omitted in Moller's review. The subject is more complex than many investigations have allowed, and the influence of tree species, age, size and stocking has been variously interpreted, but in papers dealing with green pruning of even-aged young plantations of fast growing pine species, the following generalizations emerge:

1. Diameter growth on the part of the trunk which has been green pruned may be significantly reduced when more than one third of the green crown is removed; diameter growth in the unpruned green crown above is not affected, and tree form is consequently improved (Young and Kramer, 1956 et al.). The duration of the depression of diameter increment varies with the species and site, but it is usually overcome within two to five years (Luckhoff, 1949; Sherry, 1961).

2. Height increment is affected much less than diameter increment (Moller, 1960).

3. Where pruning is carried out on selected stems only, then there is a more significant reduction of increment of the pruned, than of the unpruned stems (Jacobs, 1938).

In Kenya the recommended practice for pruning P. radiata is the removal of three-fifths of the green crown, less one whorl (Pudden, 1955); and in private plantations in South Africa about one third of the green crown is pruned – 6 ft pruning on 16 ft high trees; 12 ft pruning on 24 ft trees and 18 ft pruning on 30 ft trees of P. patula and P. elliottii (Sherry, 1961). Experience in Southland Conservancy has shown that between a third and a half of the green crown can be removed by pruning, with little permanent loss in stem
increment, and this criterion is used. Even if further study demonstrates that there is a slight loss in total increment, this could be justified economically if a greater volume of clear timber resulted. If pruning is timed to be carried out before branches die, there will be no bark-encased knots or defects except for the resin films that form around the branch stubs; these cannot be avoided.

Figure 2 shows the rise in green crown level with height growth, and the pruning steps which must be taken if neither more than half the depth of the green crown is to be removed nor any encasement of the branch bark is to occur. This figure is based on data from trees in both 8 × 6 ft and 6 × 6 ft stands. It will be noted that three steps are taken to prune the first log to 18 ft:

(1) Low pruning to remove branches to 6 ft; some trees which have long internodes will then be free of branches to 8 ft.

(2) Intermediate pruning above the low pruned level so that trees are free of all branches to 12 ft.

(3) High pruning to remove branches to 18 ft.

It may appear that three steps in place of the traditional two would cost more, but experience has shown that costs are not necessarily greater, and this has also been found in Australia (Jacobs, 1938) with P. radiata and in the United States (Bull, 1943) with longleaf pine. Three stages of pruning are also convenient for other reasons, which are mentioned later.

The Knotty Core

The knotty core is the inner part of the log which contains the branch stubs left after artificial or natural pruning. The diameter and straightness of the trees at the time of pruning have a dominant effect on the size of the knotty core. The larger the knotty core, the less the clear wood that will be grown outside it. Such theoretical computations as those of Bickerstaff (1942), Huey (1950) and Shaw and Staebler (1952), which are based on the application of diagrams of cutting patterns onto log cross sections, show that there is a marked reduction of clearwood production as the knotty core increases in diameter. Bickerstaff (1942) has calculated that for a log of 16 in. s.e.d. the proportion of clearwood produced is:

- 89 percent when the knotty core is 4 in. diameter,
- 76 percent when the knotty core is 6 in. diameter,
- 57 percent when the knotty core is 8 in. diameter,
- 33 percent when the knotty core is 10 in. diameter.

Actual published results from the sawing of pruned logs are rare however, and unpublished work of the New Zealand Forest Service suggests that theoretical yields of clearwood, on the lines of those quoted, tend to be optimistic.
Measurements of the diameter of the knotty core were made by placing a diameter tape around the largest freshly pruned branch whorl in each six- or eight-foot pruned section, and showed that for a given stocking there is a linear relationship between the maximum diameter of the knotty core and the top height of the trees. This relationship is shown in fig. 3, where the diameter of the knotty core of main crop trees is given for the different stages of pruning. To restrict the knotty core to 5 in. diameter, the advocated pruning steps would have to be carried out at top heights of 16, 22, 28, 35 and 42 ft respectively, which correspond closely to the recommended schedule of 16, 24, 29, 36 and 45 ft. These are indicated by crosses in the figure.

Fig. 3. The development of the diameter of the knotty core, and the effect of different pruning times, in relation to top height. (Corrigendum: For 0'-6" read 0'-6'.)
Size of Branches

The diameter of the branches at the time of pruning is important because the sectional area (S.A.) at the junction with the stem indicates the work necessary to prune the branch. Large knots in

Fig. 4. Change in the average and maximum branch size in the low pruned section, with tree height.
timber sawn from the knotty core limit the use of the timber. Large pruning scars take longer to heal; and the bark sliver enclosed in the healing process, together with the amount of distorted grain, are proportionately greater for large branches than for smaller ones. Figure 4 shows the increase in diameter, and the corresponding sectional area for the largest and mean branches in the first 6 ft section, measured on trees free of weed growth in a 6 × 6 ft spaced stand. It will be noted that the area of the scar approximately doubles from the fourth to the seventh year (12 ft to 24 ft top height).

When lower branches are suppressed early by weed growth, no increase in cost results from postponing pruning indefinitely. The work is easier once the weed growth is suppressed, but this is offset by the fact that bark encasement of the small branches is, by then, well advanced, and hence the diameter of the knotty core is increased.

**PRUNING**

*Numbers of Trees to be Pruned*

It is obviously wasteful to prune trees which will be thinned to waste in early thinnings, or to high prune trees which will be removed in the second thinning when insufficient time will have elapsed for more than slabwood to have grown over the branch stubs. The number of trees to be pruned is, therefore, determined by the thinning schedule, plus an allowance of 20 percent to cover losses through wind break, thinning damage and other causes.

The first thinning to waste should generally leave 250 to 300 stems per acre at age 10 years. It is these trees which will require to be low pruned to give access for further work, to provide better vision for marking for thinning and high pruning, and to make conditions more convenient for handling high pruning tools. If, however, the market allows posts to be extracted at the first thinning an additional 250 to 300 stems per acre could be pruned. Posts from pruned stems are free from nodal swellings, and trimming before peeling is eliminated. Posts from pruned trees are superior in appearance to those from unpruned trees.

Costs can be reduced if marking for pruning is done by specially trained personnel. When very experienced workmen are employed marking can be omitted.

In 6 × 6 ft stands, one tree in four is selected, which results in 300 low pruned stems per acre. By selecting from two rows, the marker has four trees close at hand and can select stems accordingly. In 8 × 6 ft spacing, one tree in three is selected from two rows. At intermediate pruning, for both spacings, one low pruned tree in three is selected. This proportion will result in a greater number
being pruned than is actually required, but this will provide the necessary reserve to allow for losses or damage.

In 6 × 6 ft and 8 × 6 ft stands there is seldom any doubt about which trees should be selected. Straightness and vigour are the first considerations, and on these factors alone there is usually one tree that is superior to the others in any group. If two or more trees are equal in these respects, then other factors such as freedom from stem cones, and angle and frequency of branching must be considered. More frequently there is no tree in the group of a high enough standard; then either the best stem available must be pruned or, if they are all grossly malformed, none of that group may be pruned at all.

**Second Log Pruning**

Pruning above 18 ft is economically and physically possible and has been carried out to 32 ft on a reasonable scale. From the data available from measurements made in two stands only, a 5 to 6 in. diameter knotty core could be anticipated provided that the pruning is done in two stages: i.e., 18 to 24 ft at 36 ft top height, and 24 to 32 ft at 45 ft top height. Figures 2 and 3 show that these steps are based on both maintaining the green crown down to the pruned level, and restricting the knotty core to about 5 in. diameter.

**Pruning Tools**

Brief mention must be made of the tools which have proved to be the most efficient for pruning in Southland Conservancy. For low pruning, provided stand top height is about 15 ft, the No. 2 Porter pruner (two handled shears) have given good results. They are quick, leave a scar that heals cleanly, and, because they cut from both the top and bottom, prevent tearing and stripping of the bark. They require little maintenance in comparison with the frequent sharpening required to keep saws in good order. There will always be an occasional branch which is too large for pruners, and in a gang of five to ten men, one or two should carry short handled saws for pruning these.

For intermediate and high pruning, the crescent saw blade of heavy gauge, of four or five teeth to the inch, and attached to a tubular aluminium handle has proved best. For high pruning, the blade is fitted into a 12 ft handle of 1.5 in. diameter aluminium tube; for intermediate pruning an aluminium or wooden handle 6 to 7 ft long suffices. Although the aluminium handles are about four times as expensive as wood, they last almost indefinitely and have much greater stiffness for less weight.

Pruning from 18 to 24 ft can be accomplished with a 16 ft tubular aluminium handle; but above this height the Swedish sectional aluminium climbing ladder, with safety belt and handgrip saw becomes a necessity if the quality of the pruning is to be maintained.
THINNING REGIMES

Early Thinning

The purpose of early thinning is fourfold:
(a) to maintain increment on pruned trees;
(b) to ensure that the pruned trees are not dominated by trees of poorer merchantable form;
(c) to keep branches alive above the pruned level until the next thinning is due; and
(d) to eliminate malformed and suppressed trees that have no merchantable potential.

If branches are to remain green on all sides of the tree it is essential that the crown be completely freed. Experience has shown that this is achieved by removing three out of four trees at 36 ft
top height in $6 \times 6$ ft stands, and two out of three trees in $8 \times 6$ ft stands. The trees removed are, of course, those that were not pruned in the first selection for low pruning. Figure 5 shows that a stand with a stocking of 250 stems per acre will not maintain a green crown from immediately above the high pruned level once the top height exceeds 58 ft at 15 years. To maintain the green crown a second thinning will then be necessary. The earliest that this second thinning should be carried out may vary according to the market available for minor forest produce, or, if to waste, on the effect of the thinning on later pruning.

If the first thinning is by felling (and not by poisoning) and takes place too early, then the effects are to increase the diameter of the knotty core, and to increase the size of the branches which are to be removed at intermediate pruning. The measurements in table 1 show the comparative development of the knotty core and branch size of the main crop trees in thinned and unthinned portions of a stand, part of which had been thinned to 250 stems per acre at age six. The measurements were made at age eight, at the time of intermediate pruning.

<table>
<thead>
<tr>
<th>Measurements taken two years after thinning</th>
<th>Thinned</th>
<th>Unthinned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average total height (ft)</td>
<td>32</td>
<td>33</td>
</tr>
<tr>
<td>Average d.b.h. (in.)</td>
<td>7.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Average knotty core dia. between 6 and 12 ft (in.)</td>
<td>8.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Ave. dia. of largest branches between 6 and 12 ft (in.)</td>
<td>1.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Average cross-section of these largest branches (sq.in.)</td>
<td>2.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

It is probable that the low cost of this very early first thinning will be offset by the higher cost of pruning larger branches and the loss of clear-timber increment due to the larger knotty core. In addition, if thinning is by felling, the slash is a hindrance to workers carrying out subsequent pruning.

The method of thinning could have some influence on the timing of the thinning. An advantage of poison thinning over felling is that the lower green branches are exposed gradually to full light (Crutwell, 1960) and a less vigorous development of these branches can be assumed. There is also no ground slash at least until the pruning operations are completed. Therefore if thinning is by poisoning, it could be carried out earlier than thinning by felling.
Initial Spacing and First Thinning

It may be thought that if a thinning to 250 stems per acre is necessary at age 10 (36 ft top height), then the initial stocking of 900–1200 stems per acre is unnecessarily high. This high initial stocking is still necessary for two reasons:

1. There may not be a sufficient number of well distributed high quality stems to leave at the first thinning; fig. 6 shows the relationship between the number of normal stems and the initial planting density. The data on which these relationships are based were taken from an unpublished report by Macarthur (1952) and are based on a large number of plots throughout the country. If the average value for the number of normal stems per acre is taken, then one half the area would have sufficient high quality stems. A proportion of two-thirds is considered to be desirable, and fig. 6 shows that an initial spacing of 7 × 7 ft or 8 × 6 ft will accomplish this.

2. At wider spacing, the branches are larger, so pruning costs are higher.

(2) At wider spacing, the branches are larger, so pruning costs are higher.

Fig. 6. Relation between number of normal form trees and overall stocking in *Pinus radiata.*
**Postulated Thinning Regime, and the Final Crop**

The development of a silvicultural schedule that adheres to these principles for the whole of the rotation must remain theoretical at present, as the stands which have been managed along these lines are too young to yield direct information. Some basic data are available however, and by checking these against various criteria, it is possible to obtain a good estimate of what might be achieved in practice.

Table 2 summarizes the proposed management schedule, together with the basic data used to derive it. An explanation then follows of the derivation of the basic data.

<table>
<thead>
<tr>
<th>TABLE 2: MANAGEMENT SCHEDULE FOR <em>P. radiata</em> IN SOUTHLAND</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age – Years:</strong></td>
</tr>
<tr>
<td><strong>BASIC DATA</strong></td>
</tr>
<tr>
<td>Dominants:</td>
</tr>
<tr>
<td>height (ft)</td>
</tr>
<tr>
<td>d.b.h. (in.)</td>
</tr>
<tr>
<td>volume</td>
</tr>
<tr>
<td>Volume per acre:</td>
</tr>
<tr>
<td>unthinned stands</td>
</tr>
</tbody>
</table>

**TENDING SCHEDULE FOR 40 YEAR ROTATION**

| Stocking: | | | | | |
| (s.p.a.) | before thinning | 900 | 250 | 160 | 100 | 70 |
| after thinning | 250 | 160 | 100 | 70 | – |
| Main crop: | | | | | |
| volume per acre | 250 | 2,500 | 3,200 | 6,000 | 9,800 |
| mean stem volume | – | 10 | 20 | 60 | 140 |
| Thinnings: | | | | | |
| volume per acre | – | 900 | 1,100 | 1,500 | – |
| mean stem volume | – | 10 | 18 | 50 | – |
| Residual crop: | | | | | |
| volume per acre | 250 | 1,600 | 2,100 | 4,500 | – |
| mean stem volume | – | 10 | 21 | 64 | – |

(All volumes are in cubic feet, to a 6 in. top diameter)

The first criterion is the maintenance of a deep green crown; the importance of which was stressed early in this paper. It is considered that by keeping a green crown down to the upper level of pruning a high rate of increment would be achieved and the grade of logs above the two pruned logs would be improved by the reduction of bark encased defects.

Whiteside (1962), in a study of green crown development of *P. radiata* at Tapanui, concluded that the depth of green crown is related to stocking, and it is possible to calculate the stocking necessary to keep the green crown down to a specified height. The two curves in fig. 5 show this for 16 ft and 32 ft for a Site Index of
75. In a young stand, thinning must be timed so that green branches will persist at the 16 or 18 ft level. After 27 years, however, only trees which have been pruned to 32 ft will remain, and the stocking will be adjusted to allow the base of the green crown to rise to this level. Thinning steps have been fitted to the curves, and the appropriate stocking per acre is incorporated in the management schedule given in Table 2.

The second important criterion is represented in Fig. 7 by a series of curves which show the maximum growth of trees that can be obtained by giving adequate growing space throughout the rotation. Such trees must have, however, reasonable branch size and form, and this qualification holds for the trees from which the data are derived. The data on which Fig. 7 is based are derived from a stand of Douglas fir near Auckland, New Zealand.
number of sources. Up to age 20, data are from two heavily thinned Forest Research Institute permanent sample plots, one at Ashley Forest, and the other at Tapanui Forest. They have been treated similarly, but not identically, and had been thinned to an intensity close to that now required. From 20 to 35 years, data from assessment plots in the forests of Tapanui District and Pebbly Hills Forest have been analysed. The plots have been segregated into groups carrying a stocking inside a range which gives the average stockings shown on the diagram. Top d.b.h. (which is the diameter corresponding with mean top height) has been calculated for each group. Finally, at 60 years, information is available from shelter belts two rows in width. The form of these shelterbelt trees is

Fig. 8. Relation between yields of thinned and unthinned stands.
excellent, but the large green branches on the outside of the rows must be offset against the dead branches on the inside: this gives an average green crown level of about 32 ft, and the average branch size would then be acceptable.

The optimum top d.b.h. curve is admittedly based on data which would normally be inadmissible in a technical paper, but the available information must be used in the 20 year interim before more precise information becomes available.

The curve of mean top height against age in fig. 1 is based on adequate data from many stands.

The two curves of mean top height (fig. 1) and top d.b.h. (fig. 7) used together give the appropriate tree volumes to a 6 in. top, as derived from the 1952 Southland Radiata Pine Volume Table. The volume of individual trees, multiplied by the stocking before or after thinning gives the respective stand volumes. Some personal judgement has been necessary to allocate a tree volume where the stocking is not the hundred top trees required. Where the stocking exceeded one hundred stems per acre, a lesser average volume has been used, and the reverse where stocking was less. The average volume of the trees removed as thinnings will be less than that of the overall stand average both before and after thinning.

A third check can be made on the proposed management schedule. It has been found, from assessment plots in thinned stands which have comparable unthinned control plots, that when a stand is thinned the volume of the remaining stems is equal to the original volume less the volume of thinnings; and that, when a thinned stand is clearfelled, the volume of the final crop plus the total thinning yields is more or less equal to the final crop volume of the unthinned stand. Figure 8 shows this in graphical form. This appears to hold as much for a 6 in. top volume as for total volume. The accumulated volume in the schedule for the proposed thinned stand is 13,300 cu.ft, which compares with 13,400 cu.ft at 40 years in unthinned stands. The yields have been rounded off to the nearest 100 cu.ft to facilitate assimilation, and in any case the method is admittedly crude and nice correlation cannot be expected.

The synthesis of the three methods of approach: maintenance of a deep green crown, maintenance of maximum diameter growth on final crop trees, and maintenance of the overall volume yield, has resulted in the regime postulated in table 2. It is anticipated that this may be modified as a result of experience, but it does provide a rational approach to the tending problems presented by an extremely fast growing species. It is hoped that this new schedule, and the basis for it, will avoid the misapprehensions now apparent in the tending of first rotation stands of *P. radiata*.
ACKNOWLEDGEMENT

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REFERENCES


