A SILVICULTURAL STAND MODEL: IMPLICATIONS FOR RADIATA PINE MANAGEMENT

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ABSTRACT

Increased understanding of the interdependence of the growth and quality of radiata pine with site, silviculture and utilisation resulted in increased problems of communications between research and management. The solution was the development of a computer based silvicultural stand model (SILMOD), which, by incorporating the accumulated research information and experience, provides predictions of the size, quality and value of a radiata pine stand given almost any New Zealand site, silvicultural treatment or rotation, and for a range of processing options.

Work with the model has shown that site factors (namely, site productivity, topography and location in relation to mill and market) have the greatest effect on forest profitability. Also important are the silvicultural decisions on the final crop stocking, rotation, the timing of pruning and thinning, and the processing factors of mill conversion and choice of minimum sawlog size. Overhead costs can also be critical.

The relative importance of these factors is illustrated by comparing two forest regimes on different Otago/Southland sites.

INTRODUCTION

Because far-sighted forefathers established a large resource of radiata pine, and because radiata pine not only grows fast but is very responsive to crop manipulation, New Zealand has achieved pre-eminence in plantation management.

At first New Zealand followed the forestry traditions of Europe and North America. Later the innovations from South Africa and Australia influenced our practice. From the early 1960s New Zealand began its own intensive silvicultural research. Then, questions appeared relatively simple and research for solutions seemed only a matter of a few well-designed trials. However, as

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results emerged it became increasingly obvious that we were not going to get clearcut management solutions from simple trials. This led to more and more trials which were more and more complex. By the late 1970s our problem was becoming one of too much information rather than too little. How could we understand and interpret all that information and experience? And, equally, how could we then communicate this in a form which the forest managers and planners could understand and use?

The first attempts at trying to resolve these problems were the economic models prepared during the late '60s and early '70s under the leadership of Dr R. T. Fenton (Fenton, 1972). These models attempted to bring together information on a range of possible silvicultural options and to compare them on a common basis. For this evaluation it was recognised that tree quality factors must be included and that it was necessary to extend the evaluation beyond the forest into processing. It was also recognised that economics rather than biological or social criteria was the only effective criterion for comparing options.

These economic studies demonstrated the superiority, both economically and silviculturally, of regimes involving a low final crop stocking which had been pruned and thinned at an early age (Fenton et al., 1972). However, there was a major problem in gaining general acceptance of the management principles involved. The reasons for this are many and include:

— A general failure to accept that economics is a valid means of comparing different silvicultural treatments.

— Difficulty of management to accept regimes for which no examples existed (this was in spite of the fact that many regimes current at the time had no long-term evidence to support them either).

— An inability to predict all the effects of a silvicultural treatment on tree quality (e.g., the effect on branch size and, in turn, the influence of branch size on timber quality).

— Limits to the number of silvicultural and processing options that could be tested — a result of both the absence of information and projection methods, and the time involved (one economic model evaluation involved at least 6 months’ work).

Our research, rather than help management narrow down the options, seemed only to increase the diversity. By the subjective weighting of the various results it was possible to justify almost
any regime. The 1970s saw throughout New Zealand a tremendous proliferation of forest management practices. All of them had some element of justification, but clearly, given such diversity, not all of them could be optimal or even be anywhere near optimal.

We believed we had in all our trials the basis for helping management. However, it was becoming obvious that we needed a totally different approach to the analysis of research information and to research communication.

THE DEVELOPMENT OF A MODELLING APPROACH — SILMOD

Early in 1978 the researchers involved held a series of internal discussions on the joint problems of the analysis of our large and growing data base and of the effective communication of our results to management. After reviewing all the information we had accumulated over the last 10 to 15 years, we concluded that the traditional means of analysing and publishing our work were completely inappropriate.

After much discussion we concluded that the only way we could solve the problem of analysis and communication was to incorporate our knowledge into a stand model which would simulate the whole growing, harvesting and conversion process. The resulting simulation model would provide predictions on how wood yields and tree quality are affected by silvicultural treatment and site, and how these in turn affect harvesting costs and the quality and value of the conversion products of pulp, sawn timber and plywood. The major difference between this and our earlier budgets was that this model was to be computer based, and could interactively examine a large number of alternative options.

At about the same time, the Director-General of Forests was becoming concerned at the proliferation of silviculture regimes throughout New Zealand, and after discussion with the Senior Management and Research Directors it was decided to set up the Radiata Pine Task Force to provide a better basis for determining and rationalising silvicultural regimes.

The Task Force was composed of both research and management staff and used as its base the mensurational systems which had been developed by an earlier group (the Mensurational Project Team). Incorporating results from silvicultural and other experiments (many of which were carried out as part of the
Task Force effort) and using an interactive computer contributed by the New Zealand forest industries, the Task Force developed a stand simulation model — SILMOD.

The SILMOD model simulates the growth of one hectare of tended radiata pine and then simulates the harvesting, transporting and sawing of that stand. The model not only predicts volume yields but also the major aspects of quality and then uses these, and other information provided by the user, to predict profitability for a range of criteria, and volumes, values, and returns by log categories. The model also provides estimates of the major timber grades, as well as conversions, etc.

One run of SILMOD takes less than a minute of computer time yet provides more information than was possible from one complete economic model of a decade ago. Such has been the progress in modelling and in computers.

The model is flexible in that it is able to simulate almost any regime (especially any combination of pruning and thinning) on a wide range of rotation lengths on almost any site (high to low productivity, and flat to very steep). All of the currently available yield models (including the Southland growth model) have been incorporated. The model selects the most appropriate harvesting system and predicts transport costs to the sawmill. Alternative sawing costs, conversion standards, sawing patterns and price assumptions can be selected. Although the computer makes many predictions as it proceeds through the simulation, almost all of these decisions can be changed by the operator and these alternative values substituted for the remainder of the simulation.

Most of the components of SILMOD have been validated but more will be done. Although work is continuing on its further development, SILMOD is extremely useful in its present form. It is particularly useful for determining not only the relative importance of the various factors but also the timing and intensity of silvicultural operations.

MAJOR INFLUENCES ON FOREST PROFITABILITY

Using SILMOD over a period of several months has shown that the following factors have a major influence on radiata pine stand profitability.

A. Site Factors

(1) Site productivity in terms of height growth as defined by site index (mean top height at age 20) and basal area develop-
ment. Site productivity is extremely important because of its influence on yield and piece size, and hence on realisations and costs.

(2) Topography or ground slope because of its influence on growing and harvesting costs, and to a lesser extent on log transport costs.

(3) The distance of the forest to the processing plant(s) because of its influence on log transport costs.

(4) The location of the processing plant(s) relative to the market (domestic market or export port) because of its influence on transport cost of processed products.

These site factors collectively are the most important group, and emphasise the critical importance of forest site selection.

B. Regime Factors

(1) Final crop stocking because of its influence on yield, log size and quality, realisations, and growing, harvesting, cartage and sawing costs. Selection of the final crop stocking is by far the most important decision in the hands of the forest manager.

(2) Rotation age. The timing of clearfelling is important because of its influence on yield, log size and quality, realisations, compounded growing costs, and harvesting, cartage and sawing costs. The selection of interest rate for compounding growing costs and for discounting net worth back to the beginning of the rotation will have a major influence on the optimum rotation age.

(3) Timing of pruning and thinning. The timing of pruning influences the quality and value of pruned logs, while the timing of thinning influences log size, and the size of branches and hence quality of unpruned logs. Also pruning and thinning costs are influenced by the timing of the operations.

C. Processing Factors

(1) Sawmill conversion standard, or factors within the sawmill that influence the log conversion percentage. The most important of these factors is the average size overcut from nominal or call dimensions.

(2) The minimum sawlog small end diameter. Logs smaller than the minimum sawlog diameter are valued as pulpwood (or
other small roundwood), or alternatively as waste by assigning a value of zero to these logs.

D. Price Factors

(1) Prices for clear grades of timber. These are important when a significant proportion of the sawn output is clear timber from pruned logs.

(2) Prices for pulpwood and chips. These are important particularly where average log size is small and a high proportion of stand volume is produced in the form of pulpwood and chip residues.

E. Overhead Costs

Overhead or administration costs can be extremely important to the point where they are so high as to make stand profitability impossible. Administration or annual overhead costs include land rental (say 6% of land value), road maintenance, fire protection, and general administrative overheads. The total can vary from $20 to $150 per hectare per annum.

EXAMPLES IN USE OF SILMOD

The importance of the site, regime and processing factors is illustrated in this paper by using the silvicultural stand model to compare two alternative radiata pine regimes grown on a range of sites representative of those in the Otago/Southland area. Each regime is grown to three alternative rotation ages, 25, 30 and 35 years.

Details of the two regimes are given in Table 1. Regime A is a regime of low final crop stocking (200 stems/ha) and with pruning and thinning carried out fairly early on current standards. This regime is infrequently represented in stands to be felled.

<table>
<thead>
<tr>
<th>TABLE 1: REGIME DETAILS (Figures per ha)</th>
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<tr>
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<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Initial stocking</td>
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<tr>
<td>Low prune (2.4 m)</td>
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<tr>
<td>First thin</td>
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<tr>
<td>Intermediate prune (4 m)</td>
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<tr>
<td>High prune (5.8 m)</td>
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<tr>
<td>Second thin</td>
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<td>Final crop stocking</td>
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before the turn of the century. Regime B is a regime regarded as being fairly representative of much of the new crop resource to be felled over the next 25 years. It is a regime with a relatively high final crop stocking (370 stems/ha) and with a pruning and thinning regime very similar, particularly with regard to pruning, to many schedules implemented over the last 20 years.

The growing costs assumed for these regimes are given in Table 2. They have been derived by using program OPCOST, which has been derived at the Forest Research Institute from Forest Service work study standards.

<table>
<thead>
<tr>
<th>TABLE 2: GROWING COSTS ($/ha)</th>
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<tbody>
<tr>
<td><strong>Regime A</strong></td>
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<tr>
<td>Slope 0-10°</td>
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<tr>
<td>Land preparation</td>
</tr>
<tr>
<td>Establishment</td>
</tr>
<tr>
<td>Administrative/yr</td>
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<tr>
<td>1st thin</td>
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<tr>
<td>2nd thin</td>
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<tr>
<td>Low prune</td>
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<tr>
<td>Intermediate prune</td>
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<tr>
<td>High prune</td>
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</table>

For the two regimes a common initial stocking to final stocking ratio of 5:1 has been used and costs derived accordingly. This ratio has been widely discussed with foresters and forest managers and has met with general, if not unanimous, approval. For both regimes an overhead or administration cost of $60/ha/yr has been used. This is a reasonably average overhead cost for Forest Service operations, although there can be considerable variation about this figure for reasons which have yet to be investigated.

The functions selected in using the silvicultural stand model to derive present net worth values for the two regimes are given in Appendix 1. In using the model the following variations in site and processing factors have been investigated.

(1) Site productivity. Site indices 20 and 25. The majority of Otago/Southland sites suitable for radiata pine fall within the 20-25 site index range. No variation in basal area productivity has been included because evidence available to date indicates that all, or the majority, of the sites in the region have similar basal area productivity. The medium fertility basal area function in SILMOD has been used for all examples as current data show this to be appropriate.
(2) Topography. Ground slopes of 0-10° and 20-35°. The majority of Otago/Southland forests will be on slopes of 0-35°. Skidder logging has been selected for a ground slope of 0-10°, and hauler logging for a ground slope of 20-35°. Logging costs have been calculated accordingly. For ground slopes of 10-20° SILMOD requires tractor logging, and the costs for this system are intermediate between those for skidder and hauler logging.

(3) Log cartage distances of 20 km and 100 km. These two figures have been selected to encompass the cartage distance range within which most commercial operations can be expected to fall.

(4) Average and high sawmill conversion standards. Average conversion standard is defined by a 2 mm size overcut in both width and thickness and a 2.4 m minimum recoverable length. The high standard is defined by a zero size overcut and a 1.8 m minimum recoverable length. For both standards the average saw kerf is 4 mm and the minimum recoverable size is 75 × 25 mm. The average standard corresponds to that obtained in commercial sawmills with reasonably modern equipment and efficient operating procedures while the high standard corresponds to the very best of current commercial practice. A considerable number of mills have conversion standards below the average defined here, but the effects of these low standards are not examined in this paper.

(5) Minimum sawlog small end diameters of 20 cm and 30 cm. A 20 cm minimum sed is fairly representative of many sawmills. A minimum of 30 cm is virtually unknown in New Zealand but is included to illustrate the effects of transferring a significant proportion of material normally regarded as sawlogs to the pulp log category. In the examples given, the pulp logs, down to a minimum sed of 10 cm, are valued at $25.29/m$^3$ delivered at pulpmill on the basis of having an average basic density of 400 kg/m$^3$. This figure, which is adjusted on the basis of actual wood density, is fairly representative of free market pulpwood prices in the North Island.

RESULTS AND DISCUSSION

The stand present net worth (PNW) values obtained by using SILMOD on regimes A and B subject to various combinations
of site index, ground slope, log haul distance, mill conversion standard and minimum sawlog sed are given in Table 3.*

SILMOD calculates the residual or net value per hectare and per m$^3$ of a stand of trees at time of felling by subtracting harvesting, cartage and processing costs from the value of sawn timber, chip residues and round pulpwood (delivered at plant). Compounded growing costs, including annual administrative overheads, are then deducted to derive the stand net worth/hectare, and finally the net worth is discounted back to the stand of the rotation to derive PNW. The cost of land is taken into account only in administrative overheads by including an annual land rent charge. However, in this paper the administrative overheads are kept constant. The value of sawn timber is derived on the basis of the grades and conversion percentages predicted by the model.

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*Between presentation and publication SILMOD has been improved and current versions would not give output exactly as in this paper. Relativities, however, remain unchanged.
### TABLE 4: COMPARISON BETWEEN REGIMES A AND B AT AGE 30 (Figures per ha)

<table>
<thead>
<tr>
<th>Site Index 25, ground slope 0-10° (skidder), 20 km log haul distance, average conversion standard, minimum sawlog sed 200 mm.</th>
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<tbody>
<tr>
<td><strong>Regime A</strong></td>
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<tr>
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<tr>
<td>Utilisable log volume to 10 cm top (m$^3$)</td>
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<tr>
<td>Sawlog volume to 20 cm top (m$^3$)</td>
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<tr>
<td>Mean sawlog small end diameter (mm)</td>
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<tr>
<td>Mean sawlog conversion (%)</td>
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<tr>
<td>Timber volume (m$^3$)</td>
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<tr>
<td>Timber value ($)</td>
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<tr>
<td>Chip volume (m$^3$)</td>
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<tr>
<td>Chip value ($)</td>
</tr>
<tr>
<td>Sawn timber and chip value ($) (gross sawlog value)</td>
</tr>
<tr>
<td>Pulp value ($)</td>
</tr>
<tr>
<td>Total gross revenue ($) (A)</td>
</tr>
<tr>
<td>Compound growing costs ($)</td>
</tr>
<tr>
<td>Harvesting costs ($)</td>
</tr>
<tr>
<td>Cartage costs ($)</td>
</tr>
<tr>
<td>Sawing costs ($)</td>
</tr>
<tr>
<td>Total compounded costs ($) (B)</td>
</tr>
<tr>
<td>Net worth ($) (A−B)</td>
</tr>
<tr>
<td>Present net worth ($) -10% discount rate</td>
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<td>Internal rate of return (%)</td>
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</table>

Table 4 gives a detailed comparison between the two regimes for common rotation age (30) and for the same conditions of site and processing.

These tables illustrate the following points:

1. For any combination of site and processing factors, and for any rotation age selected, regime A is substantially more profitable than regime B. The difference in present net worth between the two regimes varies from $511/ha to $1163/ha depending on the combination of site, processing and rotation age variables. At least 80% of the margin that regime A has over regime B is due to the lower final crop stocking, while the remaining benefit is due to the earlier pruning/thinning schedule.

2. Table 4 shows that the gross revenues per hectare for the two regimes are fairly comparable, the lower volume/ha from regime A being almost exactly compensated for by the higher value/m$^3$. The higher value/m$^3$ from regime A is due mainly to the larger average log size, resulting in a higher sawn conversion percentage and an improved clearwood yield from pruned logs. The big difference in present net worth values between
the two regimes is almost entirely due to the much lower costs associated with regime A, particularly sawing and growing costs, but also harvesting and cartage costs. About 40% of the lower sawing cost with regime A is due to the reduced sawlog volume and about 60% due to the lower unit cost associated with larger average log size. The lower growing cost is due to the much lower number of trees requiring establishment and subsequent tending, and to a lesser extent, to pruning and thinning costs being reduced because of being carried out earlier than in regime B. The lower harvesting cost is due partly to the lower unit cost associated with larger piece size. The reduction in cartage cost is due entirely to the lower volume/ha.

(2) The change in present net worth with change in rotation age from 25 to 35 years varies from $138 to $614/ha depending on the regime and the combination of site and processing variables. Where the minimum sawlog sed is 20 cm, the variation in present net worth with changing rotation age is much greater for regime B than regime A, but where the minimum sawlog sed is 30 cm, the variation for regime B is substantially reduced to the point where it is less than for regime A.

In every example in Table 3 the optimum rotation age for three ages selected is 30 or 35, and never age 25. The general trend is for regime A to have a shorter optimum rotation age than regime B. Extensive use of SILMOD has shown that optimum rotation age can vary from 20-25 years for low-stocked regimes on highly productive sites of flat topography close to processing plants, to 45 years or longer for high-stocked regimes on steep sites of low productivity remote from processing plants.

(3) A drop in site index from 25 to 20 causes a large reduction in present net worth, varying from $369 to $713/ha depending on regime and rotation age, for constant topography, log haul distance and processing.

The effect of site index change is greater for regime A than regime B, and for both regimes the effect decreases as rotation age increases.

(4) A change in topography from 0-10° to 20-35° reduces present net worth values by $387 to $682/ha according to regime and rotation age, for constant site index, log haul distance and processing.

The effect is greater for regime B than regime A, and for both regimes decreases as rotation age increases.
(5) A change in log haul distance from 20 km to 100 km reduces present net worth values by $202 to $344/ha depending on regime and rotation age, for constant site index, topography and processing. The effect is greater for regime B and for both regimes decreases as rotation age increases.

(6) Where there are simultaneous changes in site index (25 to 20), topography (0-10° to 20-35°) and log haul distance (20 km to 100 km) present net values drop dramatically by $991 to $1379/ha depending on regime and rotation age. The reductions are comparable for the two regimes and for both regimes the reductions decrease as rotation age increases.

(7) A change in mill conversion from average to high, with constant site factors and minimum sawlog sed, increases present net worth values by $178 to $269/ha depending on regime and rotation age. The changes are similar for the two regimes and decrease as rotation age increases.

(8) A change in minimum sawlog sed from 200 mm to 300 mm, with constant site factors and mill conversion standard, increases present net worth values by $40 to $374/ha depending on regime and rotation age. The increases are much greater for regime B than regime A, and for both regimes by far the greatest increase is at rotation age 25. In all cases stand profitability is increased by sending logs between 200 mm and 300 mm sed to the pulpmill and receiving a delivered price of $25.29/m³ (density adjusted) rather than sawing them in a bandmill. The effect is most marked where there is a high proportion of these small diameter logs, namely, in high-stocked stands felled at any early age such as stand B at age 25. This means that, as sawlogs, the 200-300 mm sed logs are worth less than $25.29/m³ delivered at mill. The effect of changing the minimum sawlog sed is, of course, very interdependent with the price obtained for pulpwood.

(9) Where the mill conversion standard is changed from average to high and the minimum sawlog sed is increased from 200 mm to 300 mm, present net worth values are increased by $208 to $554/ha depending on regime and rotation age (site factors constant). The effect is greater for regime B than regime A and decreases as rotation age increases.

CONCLUSIONS

The examples given in this paper illustrate the considerable influence of site, regime and processing factors on the profitability of radiata pine forest management in the Otago/Southland region.
The factors are similarly important in other geographic localities in New Zealand. The site factors are the most important and clearly indicate the undesirability of establishing forests on steep country of low productivity remote from processing plants and markets. If the site factors are collectively adverse, then there is little or no chance that the forest will ever make a profit, regardless of the quality of forest management. On the other hand, if the site factors are favourable then there is the opportunity for highly profitable management.

The evidence is clear that in Otago/Southland, as in other parts of the country, regimes of low final stocking are likely to be much more profitable than regimes of high final stocking in spite of the lower volume production. Extensive use of SILMOD has shown that maximum volume production, which requires high stockings, is incompatible with maximum profitability. Optimum rotation age can vary considerably according to the combination of regime, site, price and processing factors.

The importance of mill conversion standard and minimum sawlog small end diameter have been illustrated. Considerable improvements in profitability can be achieved by reducing the average size overcut in the sawmill by sawing accurately to the minimum dimensions required, and by ensuring that logs that are too small to saw economically are diverted to pulpwood or some other wood use where markets for these products exist.

REFERENCES

APPENDIX 1
Silvicultural Stand Model
Functions selected for derivation of present net worth values

PROGRAM EARLY
Age/height curve — Southland (Garcia).
Diameter over stubs model — Southland.
Basal area model — medium fertility.
Minimum pulp log small end diameter — 10 cm.

PROGRAM KGM2.
Growth model — SGML.
**PROGRAM PROD.**

Tree volume table — *P. radiata*, Otago Coast (No. 126).
Taper function — *P. radiata* young crop (No. 1).
Weibull function — *P. radiata*, Rotorua Conservancy (No. 1).
Breakage function — *P. radiata*, Kaingaroa (No. 1).

**PROGRAM HARPCE.**

Topography codes — 0-10° (skidder extraction) and 20-35°* (hauler extraction).
Log cartage distance (one way) — 20 km and 100 km.
Road construction cost/km — $7500 (0-10°) and $15000 (20-35°).

**PROGRAM PREVAL.**

Wood density class — low.
Log sweep class — average.
Internode length class — Berwick.
Price for 100 × 50 mm No. 1 F grade — $147.42/m³ (green, rough sawn, whole).
Net return for sawmill chips* — $15.17/m³.
Pulpwood price delivered at mill* — $25.29/m³.
Sawmill conversion standard — average (2 mm size overcut) and high (0 mm size overcut).
Sawmill type (for sawing costs) — band mill.
Minimum sawlog small end diameter — 20 cm and 30 cm.
Present net worth interest rate — 10%.
Consumer price index (for updating timber prices, harvesting, cartage and sawing costs) — 1254.
Differential in freight — 0.
Price for clears — low (82% premium above No. 1 F grade in 100 × 50 mm size).
Grading method for framing — visual grading to NZS 3631, grading for maximum value.
Sawing pattern selection —
  Pruned logs — 25 mm thick timber.
  Unpruned logs < 35 cm sed — maximum of 100 × 50 mm timber (saw pattern 1).
  Unpruned logs ≥ 35 cm sed — 50% to maximum of 100 × 50 mm timber (saw pattern 1) and 50% to maximum of 200 × 50 mm timber (saw pattern 3).

*Prices relate to mean wood basic density of 400 kg/m³.
Actual prices adjusted on the basis of actual wood basic density.