STANDPAK EVALUATION OF THE EFFECTS OF SITE, SILVICULTURE, AND GENETICS ON MEAN LOG AGE AND THE PROPORTION OF JUVENILE WOOD

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(Received for publication 3 October 1997; revision 14 May 1998)

ABSTRACT

Recent developments in the stand modelling system STANDPAK have allowed the prediction of Mean Log Age, growth rings per small-end diameter (s.e.d.), juvenile wood volume, and the proportion of juvenile wood. This capability was used in a theoretical exercise with *Pinus radiata* D.Don to examine the influence of a number of site, silvicultural, and genetic factors on Mean Log Age and the proportion of juvenile wood in New Zealand domestic log grades.

Sensitivity analysis of individual factors and/or comparisons between simulations of major forestry management practices indicated that Mean Log Age was affected by felling age, tree stocking, and site quality. The proportion of juvenile wood in merchantable log volumes was found to be affected most by felling age, the number of growth rings containing juvenile wood, and site quality. Silvicultural factors (pruning severity, timing of thinning, and tree stocking) had a relatively small effect. Genetic improvement expressed as a Growth and Form (GF) rating, was indicated in this study to have little effect on the proportion of juvenile wood.

An examination of historic changes in silvicultural regime, felling age, and site quality of *P. radiata* forests in the central North Island indicated increases in the proportion of juvenile wood resulting from modern practices that may explain the current concerns about wood quality.

Inclusion of log age or number of rings/s.e.d. as additional criteria in the current system of log grading, should better segregate logs by the proportion of juvenile wood and wood density.

Keywords: STANDPAK; juvenile wood; log age.

INTRODUCTION

The recent concern regarding the wood quality of the current crop of *Pinus radiata* (typically harvested at age 24–28 years) has engendered discussion on whether changes in site, genetics, silvicultural regime, and felling age have influenced wood quality attributes. The perception of many in the forestry sector is that the tree crop currently harvested is of lower quality and has many problems when processed.

Changes in wood properties associated with changes in felling age and management practices have been signalled by researchers for some time (Cown & McConchie 1982, 1983; McConchie & Cown 1984; Cown *et al.* 1988; Cown 1992b).

New management practices, particularly reducing rotation age, are expected to produce logs containing a greater proportion of juvenile wood. Cown (1992a) claimed that the average diameter of juvenile wood would increase from 160 mm to 185 mm as the "old crop" was replaced by "new crop" wood. However, there has been little reported that quantifies the expected changes in the proportion of juvenile wood, i.e., how much of the resource is likely to be juvenile wood under differing site and management options.

Juvenile wood at all stem levels contains wood of lower density, lower latewood percentage, higher spiral grain angles, shorter tracheids (Cown 1992a, b), and higher microfibril angles (Donaldson 1993). A high proportion of compression wood is also common in the juvenile wood core. These attributes are known to be major causes of low strength and stiffness, and contribute to drying degrade. Although changes in these wood properties from the pith outwards are gradual, the inner 10 annual rings are usually considered, in New Zealand and Australia, to represent the juvenile wood or corewood zone (Cown 1992a).

An empirical stand modelling system for plantation forests—STANDPAK (Whiteside 1989)—has been developed at the New Zealand Forest Research Institute over the last 20 years. This computer-based system provides a mechanism for the integration of numerous research results and gives managers a method of objectively evaluating silvicultural regime options. STANDPAK predicts the growth of stands (allowing for the effects of site, genetic improvement, and management), calculates diameter and height distributions at harvest, and produces stand volumes by log size and quality. Potential sawlog values may then be predicted under a range of processing and pricing scenarios. The effects of trees on pasture and hence livestock production in agroforestry situations can also be predicted.

The modelling system has options for predicting the impact of site, silvicultural regime, and felling age on log quality variables such as s.e.d., taper, branch size, defect core size, and Pruned Log Index (PLI) (Park 1989). Factors such as wood density, sweep, and internode length can also be set by the user and distributed by tree size and log height class.

Recent developments in STANDPAK (version 6.2) have provided the ability to predict Mean Log Age (mean of the number of growth rings at each end of the log), the number of rings in the log s.e.d., juvenile wood volume, and the proportion of juvenile wood.

To examine the influence of site, genetics, and stand management treatments on the proportion of juvenile core at harvest, a theoretical exercise was undertaken using STANDPAK v6.2. This paper gives results from this exercise, and attempts to identify stand management practices that could minimise juvenile wood. The influence of the historic changes in growing practices in *P. radiata* forest in the central North Island on juvenile wood is also examined.

Developments Within STANDPAK

Mean Log Age

Mean Log Age and the number of growth rings per s.e.d. are now predicted using version 6.2 of the LOG MAKING and LOGRADES modules. The age at which a specified log begins to be formed can be predicted from the height growth of the tree, using the height/age relationship within the growth modelling routines. For each log "cut" within the modelling system, the age at the base of the log and at the top of the log is predicted. From this age and a given felling age, the number of rings at each end of the log is predicted. *Mean Log Age* is a simple arithmetic mean of the number of rings at each end of the log and is not weighted by the wood volume within each ring.

Juvenile wood

Juvenile wood volume and the percentage of juvenile wood per log grade are also predicted using version 6.2 of the LOG MAKING and LOGRADES modules.

In this procedure, juvenile wood is defined in terms of number of juvenile growth rings set by the user. Tree diameter at breast height (dbh) and height are derived for the age at which the last juvenile ring was formed in the bottom and top of each log. Taper equations are then used to predict the diameter of the juvenile core at the upper and lower ends of each log. The logic of this methodology is sound, but validation studies with actual measurements have not been undertaken.

Prediction of both Mean Log Age and juvenile wood volume was based on the following assumptions:

(a) In using a height/age curve to calculate tree height when juvenile wood is formed, it is assumed that there is no inter-change of dominance through time.

(b) Over the period prior to a pruning lift that defines an element (or subset of trees) in a stand, there is no change in the ratio of :

- subset mean dbh to stand dbh
- subset mean height to stand mean top height (MTH).

METHOD

Base Scenario

A sensitivity analysis was undertaken by defining a base scenario of GF rating, site, and silviculture. Variations to the base case were then tested with numerous runs through the modelling system. This methodology was adopted to provide results in a comparative sense and to identify possible trends. It was not expected to provide absolute data, and no statistical analysis has been attempted.

The base scenario could be considered representative of a direct sawlog regime on an average central North Island pumice plateau forest site, with pruning in three lifts to 6.5 m and thinning at the first and third pruning lifts (Table 1).

TABLE 1–Base scenario settings in STANDPAK

Factor	Level
Juvenile wood definition	First 10 rings
GF rating	14
Pruning severity	4 m crown*
Timing of thinning	6.9 m and 11.3 m MTH
Final crop stocking	300 stems/ha
Rotation age	30 years
Site quality	Medium

* Green crown length remaining after pruning

Variations to Base Scenario

Each factor was varied up and down by a level experienced in practice by New Zealand's forest industry. The effects of variations from a base scenario were assessed in terms of log grade volume, Mean Log Age, and proportion of juvenile wood.

Number of rings

Although some juvenile wood characteristics are known to be under genetic control (e.g., spiral grain—Sorensson *et al.* 1997), the family or clonal information on juvenile wood characteristics has not yet been built into STANDPAK. However, the number of rings that define juvenile wood in STANDPAK can be set between 5 and 15 rings; this in effect can simulate genetic control. Settings of 7 and 13 rings were tested as variations on the 10-ring setting in the base case.

Growth and Form (GF) rating

The effect of GF rating has been built into STANDPAK as a growth rate modifier. The effect of this on juvenile wood was tested using variations of GF7 and GF22 as a comparison to the base level of GF14.

Pruning severity

Pruning severity was varied by changing the length of green crown after pruning to 3 m and to 7 m. This effectively changed the target diameter over pruned stubs (DOS) from17 cm to 12 and 22 cm. Four pruning lifts were required to achieve a 12-cm DOS. In all other scenarios pruning was in three lifts (unless stated otherwise) and crown remaining was maintained at approximately 4 m.

Timing of thinning

The base regime was designed as a direct regime with thinnings at the first and third pruning lifts. The following variations were made to this case:
(1) Second thinning was delayed to 18 m MTH
(2) First thinning was omitted, leaving the stand unthinned until 18 m MTH
(3) As for (1) above, but with pruning to 8.5 m.

Tree stockings

To test a range of tree stocking regimes a constant selection ratio of 3:1 was maintained. Tree stockings to achieve three regimes resulting in three final-crop stockings are given in Table 2.

Rotation age

To test the impact of age of felling, rotation ages of 22, 26, and 34 years were tested as variations to the base scenario of 30 years.

Site quality

As variations on the medium site quality assumed in the base scenario, a low-quality site and a high-quality site were also tested. These site scenarios represent:

TABLE 2–Regimes to test tree stocking

Operation	Stems/ha		
Plant	600	900	1200
Prune 1	300	450	600
Prune 2	250	375	500
Prune 3	200	300	400
Thin 1@p1*	300	450	600
Thin 2@p3†	200	300	400
Final crop	200	300	400

* First pruning lift at 6.9 m MTH
† Third pruning lift at 11.3 m MTH

Low — a nitrogen-deficient, North Island west coast sand-dune forest.
Medium — a central North Island pumice plateau forest
High — a fertile ex-farm site in the Bay of Plenty or Hawke's Bay.

The models chosen for these sites are detailed in Table 3. GF rating and rotation age were kept constant in these comparisons. Volume and taper functions were chosen in consultation with Mr A. Gordon (New Zealand Forest Research Institute), with consideration given to their data source, data range, and form factor.

TABLE 3–Details of the variations used to test the effect of site quality.

Level	Low	Medium	High
Site Index (m)	26	30	30
EARLY growth model	Low	Medium	High
Later growth model	Sands	PPM88	Napirad
DOS* (cm)	15	17	20
Height model	27	34	26
Volume function	236	237	214
Taper function	236	237	214
Breakage function	1	1	1
Rotation age (years)	30	30	30

* All pruning was to a 4-m crown remaining

Log Making and Grading

The standard New Zealand domestic log grade specifications (Whiteside & Manley 1987) were used for all scenarios (Table 4). Where pruning was to 8.5 m, two 4.1-m pruned logs were cut.

Aggregations of grades

To simplify results for the numerous factors varied in this study, log grades were aggregated as given below. Aggregations for the unpruned logs amalgamate grades with the same small-end diameter.

Pruned = P500+P400+P300
S1L1 = S1+L1

TABLE 4–Log grade specifications

Grade	Min. s.e.d.	Max. branch	Max. sweep class	Min. length	Max. length
P500	500		1	4.1	6.5
P400	400		1	4.1	6.5
P300	300		1	4.1	6.5
S1	400	7	1	5.5	5.5
S2	300	7	1	5.5	5.5
S3	200	7	1	5.5	5.5
S4	150	7	1	5.5	5.5
L1	400	14	1	5.5	5.5
L2	300	14	1	5.5	5.5
L3	200	14	1	5.5	5.5
L4	150	14	1	5.5	5.5
Pulp	100	–	2	3.7	

S2L2 = S2+L2
S3L3 = S3+L3
S4L4 = S4+L4
Pulp = Pulp

RESULTS

Results are first given for the base scenario and then for each variation tested.

Base Scenario

Log grade distribution

Log volumes by individual grade were derived for the site and regime conditions of the base scenario (Fig. 1).

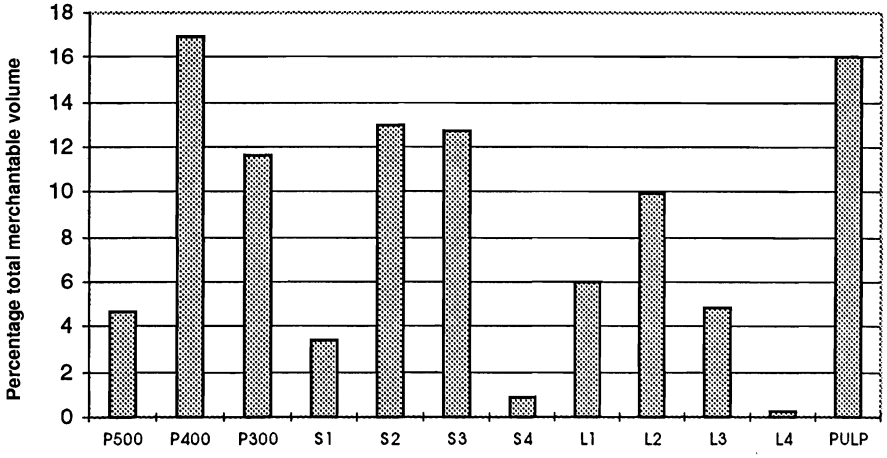

FIG. 1–Log grade distribution—base scenario.

Log grades with the highest proportion of merchantable volume were the P400, P300, S2, L2, and pulp. Very small volumes of S4 and L4 logs were produced. The P500, S1, and L3 grades each represented less than 5% of the total volume.

Where factors had been varied in the sensitivity analysis, results were simplified by using aggregated log grades. Felling age had a considerable influence on log grade distribution (Fig. 2). Pruned logs, S3L3, and Pulp grades all reduced with older felling ages while S1L1 and S2L2 increased.

Mean Log Age

The predicted Mean Log Ages by grade for the base scenario with a rotation age of 30 years are given in Fig. 3. Mean Log Age of logs cut from above the pruned butt logs was highly related to log grade as specified by s.e.d. The Pulp grade was noticeably older on average than some of the smaller s.e.d. sawlog grades. This was because some of the older aged sawlogs were downgraded to Pulp because they exceeded the specifications for sweep or branch size.

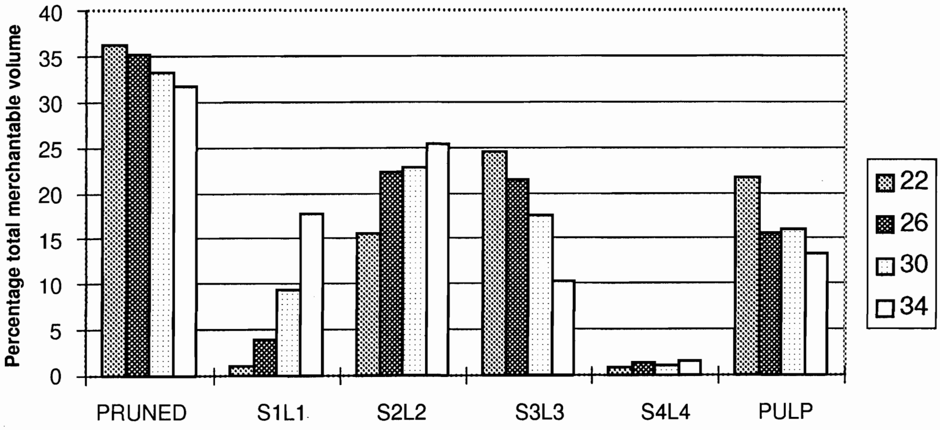

FIG. 2–Aggregated log grade distribution—effect of felling age.

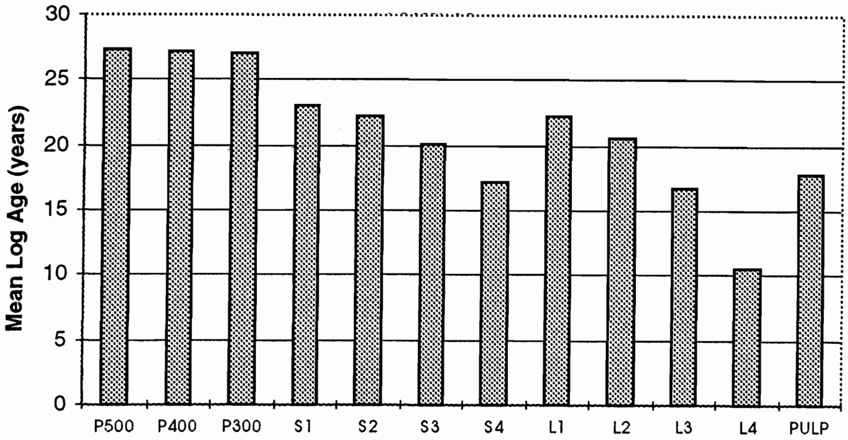

FIG. 3–Mean Log Age by individual grade—base scenario.

The effect of felling age on Mean Log Age for each log grade aggregation is given in Fig. 4. For all log grade aggregations there was a clear trend of Mean Log Age increasing with felling age, with the trend being more pronounced for the pruned logs and less pronounced for the smaller unpruned grades.

Of the other factors tested in this study, only stocking (Fig. 5) and site quality (Fig. 6) had any influence on log age. These effects were primarily in the smaller S3L3 and S4L4 grades.

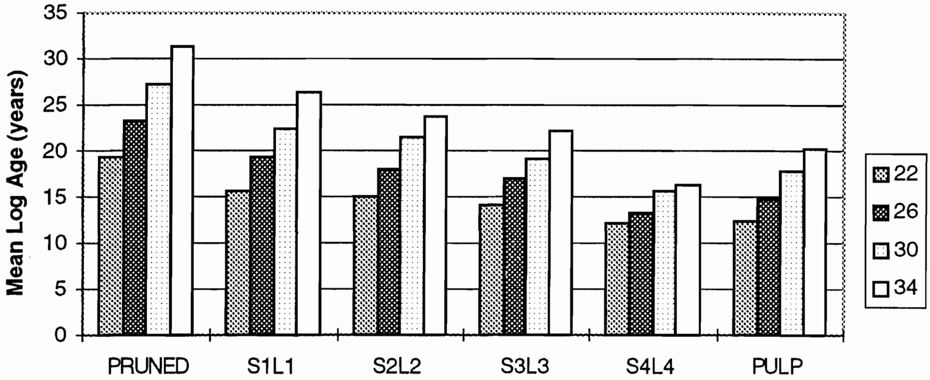

FIG. 4–Mean Log Age by aggregated log grades—effect of felling age.

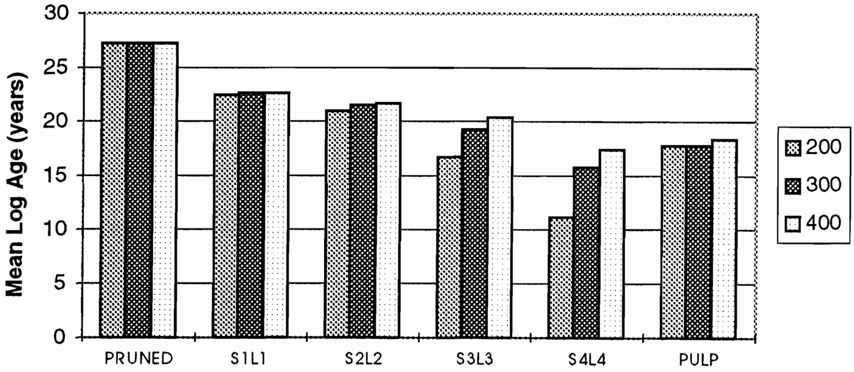

FIG. 5–Mean Log Age by aggregated log grades—effect of final-crop stocking.

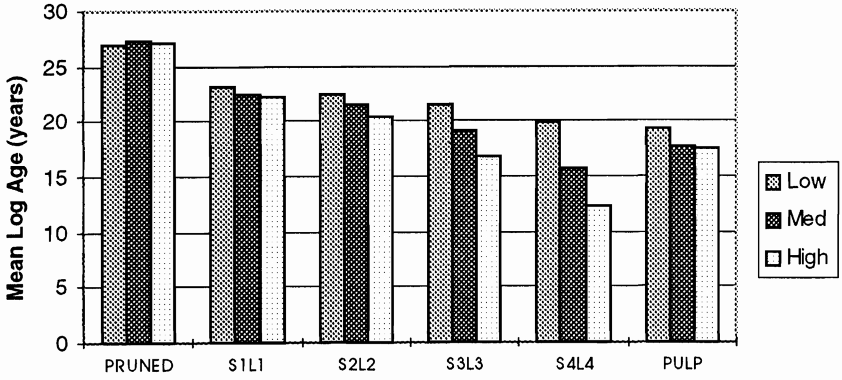

FIG. 6–Mean Log Age by aggregated log grades—effect of site quality.

Juvenile wood

The proportion of juvenile wood was examined first for individual log grades arising from the base scenario at age 30 (Fig. 7). The proportion of juvenile wood was least in the pruned butts and was indicated to increase with reducing log s.e.d. for the unpruned grades. Generally L grade logs had more juvenile wood than S grade logs for the same s.e.d. This was due to the within-stand distribution of branch sizes in STANDPAK which allocates the larger branches to the larger trees.

Although the base scenario was relatively conservative with felling at age 30, the general level of juvenile wood was noticeably high. Most unpruned logs were indicated to contain 45–60% juvenile wood.

Number of Rings Defining Juvenile Wood

A major assumption in the base scenario of this exercise was the definition of juvenile wood as the first 10 rings. To test the sensitivity of this assumption the base scenario was also tested with juvenile wood set at 7 and 13 rings (Fig. 8).

As expected, the proportion of juvenile wood in all grades was directly influenced by the number of rings defining the juvenile wood zone. For the base scenario, changing the

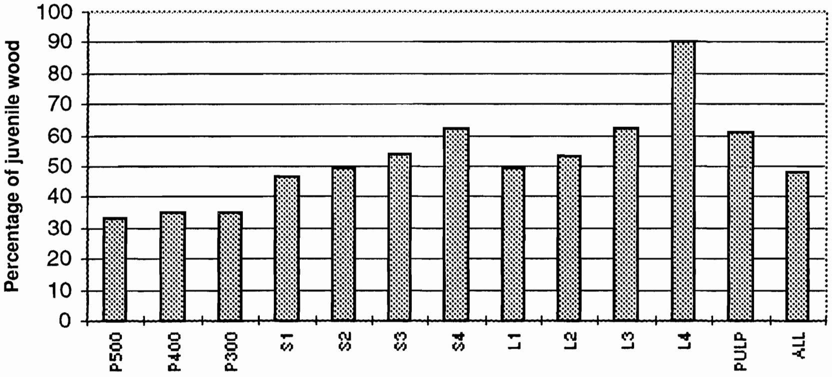

FIG. 7–Proportion of juvenile wood by log grade—base scenario.

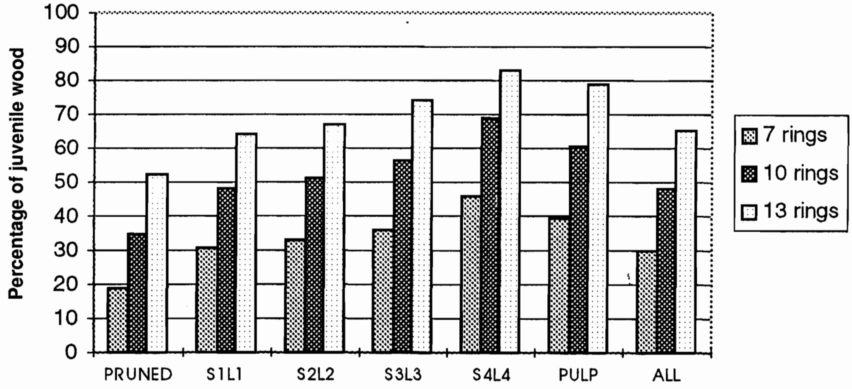

FIG. 8–Effect of number of rings on proportion of juvenile wood.

definition by ±3 rings influenced the proportion of juvenile wood by approximately ±15%, or 5% per ring.

GF Rating

To test the effect of GF rating, this factor was varied between GF7 and GF22. GF rating had little effect on juvenile wood (Fig. 9). For the Pruned and S1L1 grades, increasing GF brought a slight reduction in juvenile wood. For the S4L4 grades (with little volume) the reverse occurred.

Pruning Severity

The effect of pruning severity was tested by implementing schedules that achieved a 3-m and a 7-m crown remaining. Changing pruning severity had little effect on the proportion of juvenile wood (Fig. 10). The greatest effect appeared to be in the pruned logs where juvenile wood changed by ±4%.

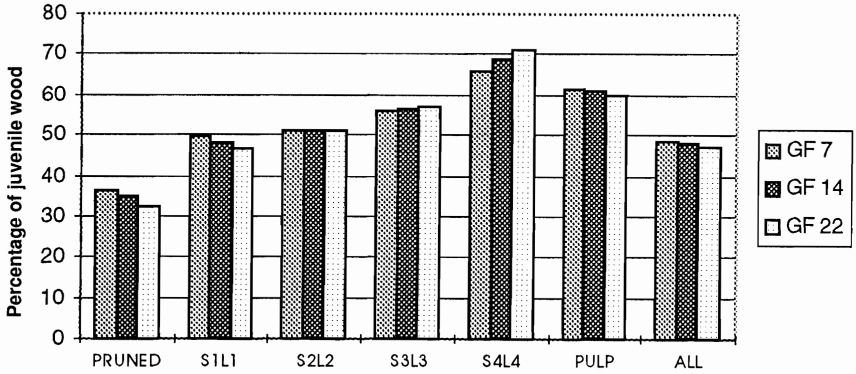

FIG. 9–Effect of GF rating on proportion of juvenile wood.

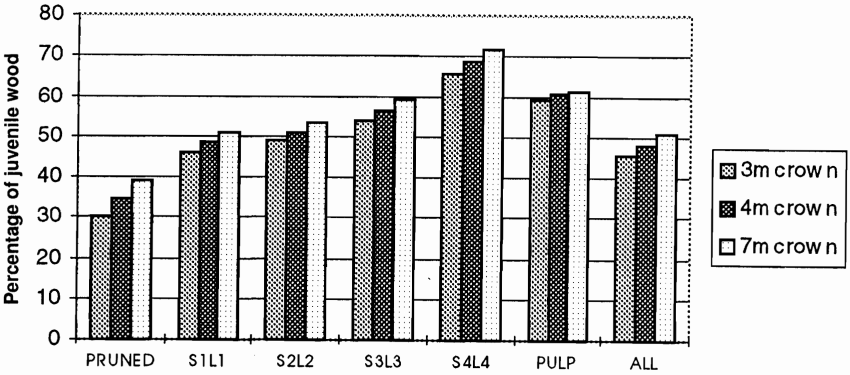

FIG. 10–Effect of pruning severity on proportion of juvenile wood.

Timing of Thinning

To test the effect of timing of thinning, the direct regime of the base scenario was modified with a number of variations (Fig. 11). Delay of the second thinning to 18 m gave a small

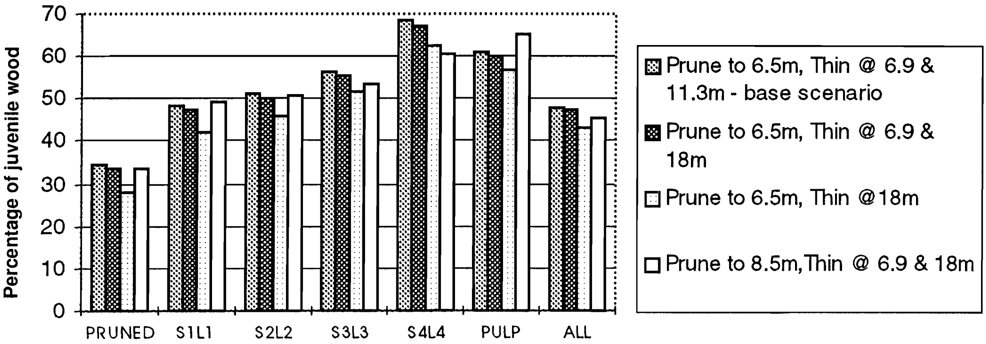

FIG. 11–Effect of timing of thinning and pruning to 8.5 m on proportion of juvenile wood.

reduction (1.5%) over all grades. Having only a single thinning at 18 m MTH had a more marked effect, reducing juvenile wood by 5% over all grades. Pruning to 8.5 m had little impact on the proportion of juvenile wood.

Tree Stocking

In this study a constant selection ratio of 3:1 (planted : final thinning) was applied to all three regimes tested. These regimes achieved three final crop stockings: 200, 300, and 400 stems/ha.

Tree stocking had little effect on the proportion juvenile wood at age 30 years (Fig. 12). The greatest changes were in the pruned logs where the proportion of juvenile wood increased with stocking, and in the smaller unpruned S3L3 and S4L4 grades which showed the opposite trend. This appeared to be due to the fact that later diameter growth at the 200 stems/ha stocking was greater than at the 400 stems/ha stocking. This created more mature-wood in the lower logs and more juvenile wood in the upper logs.

Absolute volumes of juvenile wood can also be predicted within STANDPAK. The effect of stocking on the juvenile wood volume and total merchantable volume per hectare is given in Fig. 13. Although more wood was produced at higher stockings, greater volumes of

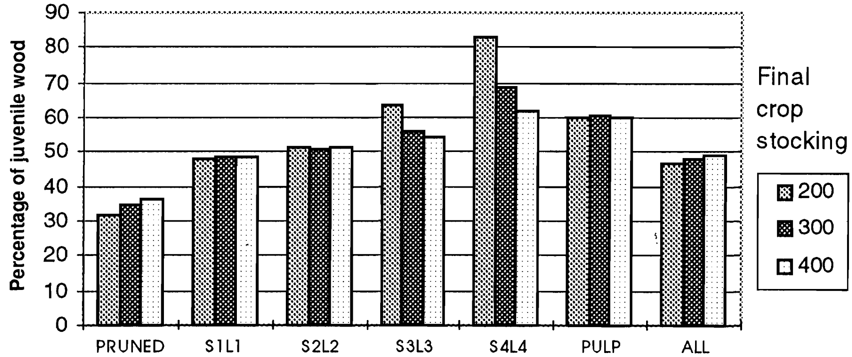

FIG. 12–Effect of tree stocking on proportion of juvenile wood.

juvenile wood per hectare would also need to be processed. In the 300 stems/ha regime approximately 300 m^3 juvenile wood/ha was produced at age 30 years.

Tree stocking can also have an impact on the distribution of log grades (Fig. 14). Increasing tree stocking decreased the proportion of volume in the pruned and larger unpruned grades. There was a corresponding increase in the proportion of smaller unpruned logs.

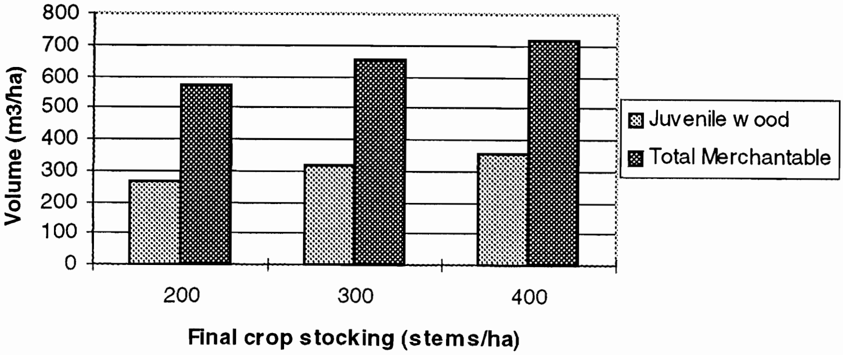

FIG. 13–Effect of tree stocking on total and juvenile wood volume.

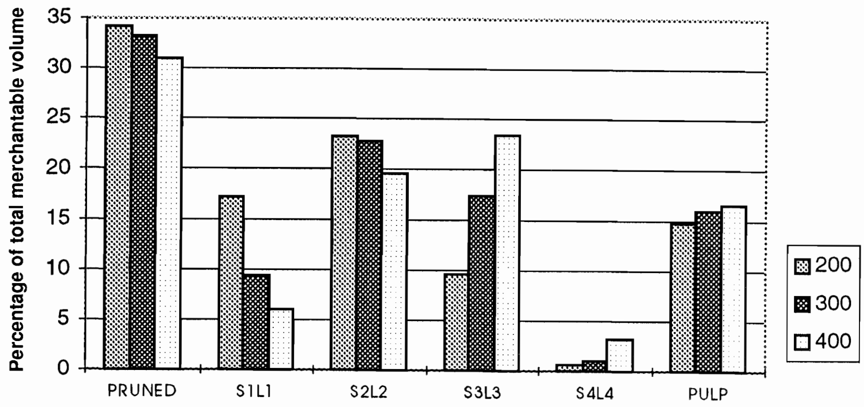

FIG. 14–Effect of final-crop stocking on log grade distribution.

Felling Age

For the base scenario the felling age was varied from 30 years to 22, 26, and 34 years. The proportion of juvenile wood increased dramatically with reduced felling age (Fig. 15). This effect was more pronounced in the smaller log grades. Generally, a reduction of felling age from 30 years to 26 years increased juvenile wood by 6% over all grades, or approximately 1.5% per year.

Site Quality

Three levels of site quality were included in the analysis. For all log grades site quality had a significant impact on the proportion of juvenile wood (Fig. 16). As site quality

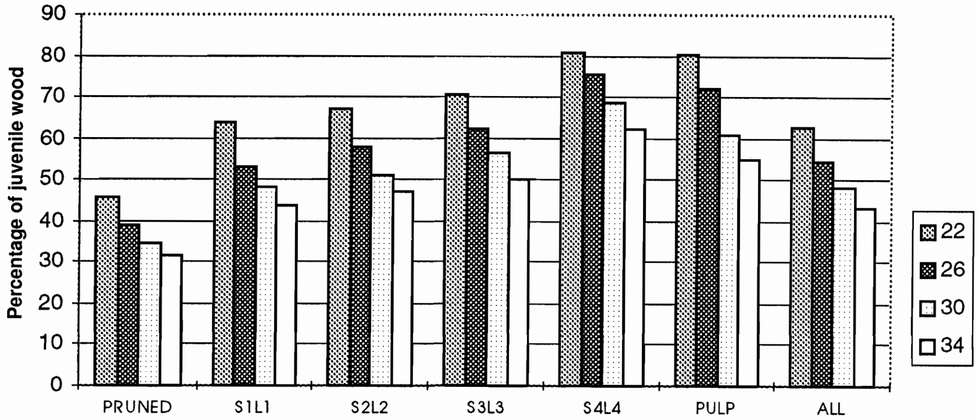

FIG. 15–Proportion of juvenile wood by log grade and felling age.

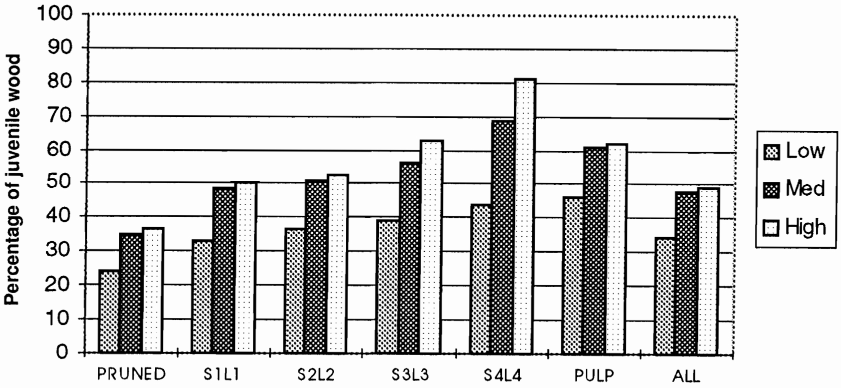

FIG. 16–Effect of site on proportion of juvenile wood.

increased the proportion of juvenile wood increased. Over all grades, the proportion of juvenile wood at age 30 was as follows: low-quality site 34.4%, medium-quality site 48.0%, high-quality site 48.9%. The difference between medium and high site qualities may appear greater than this as presented in Fig. 16 because there was very little volume in some log grades and hence they had little effect on the mean value.

Comparison of Factors

Each of the numerous factors tested showed a range of effects on the proportion of juvenile wood (Table 5). Clearly, the number of rings containing wood with juvenile characteristics had a major influence on the proportion of juvenile wood. While this may be manipulated under genetic control in future forests, it cannot be changed in the current forest estate.

Felling age can also have a large effect on the proportion of juvenile wood. While this factor may be driven largely by economic and wood flow considerations, wood quality, as indicated by the proportion of juvenile wood, appeared to be directly influenced by felling age.

TABLE 5–Relative effect of various factors on the overall proportion of juvenile wood

Factor	Variation	Juvenile wood (%)	Difference from base scenario value
Number of rings	7	29.8	–18.2
	10	48.0	
	13	65.3	+17.3
GF rating	7	48.8	+0.8
	14	48.0	
	22	46.9	–1.1
Pruning severity	3 m crown remaining	45.3	-2.7
	4 m crown remaining	48.0	
	7 m crown remaining	50.9	+2.9
Timing of thinning	Prune to 6.5 m, thin @ 6.9 & 11.3 m	48.0	
	Prune to 6.5 m, thin @ 6.9 & 18 m	47.1	–0.9
	Prune to 6.5 m, thin @18 m	43.0	–5.0
	Prune to 8.5 m, thin @ 6.9 & 18 m	45.6	–2.4
Tree stocking (final-crop stocking stems/ha)	200	46.6	–1.4
	300	48.0	
	400	48.9	+0.9
Felling age (years)	22	63.0	+15.0
	26	54.4	+6.4
	30	48.0	
	34	43.1	–4.9
Site quality	Low	34.4	–13.6
	Medium	48.0	
	High	48.9	+0.9

Site quality was very significant, particularly in the difference between the low-quality scenario and the other two scenarios,. This indicated that slow-growing sites may produce wood with a low proportion of juvenile wood.

Silvicultural factors such as pruning severity, timing of thinning, and final-crop stocking, had little influence on the proportion of juvenile wood. When combined, these factors might be useful in assisting in the reduction of juvenile wood but would not be a major influence. Pruning severity appeared to have its greatest influence on the juvenile wood of butt logs.

GF rating, as built into STANDPAK, had little effect on juvenile wood. A weak trend indicated that stands of higher GF stock would have slightly less juvenile wood.

Historic Trends in Juvenile Wood

To examine the historic changes in the proportion of juvenile wood, regimes were simulated for the central North Island "old crop" (untended except for natural thinning through Sirex wood wasp mortality, 3000 stems/ha planted) harvested at age 50 years and "transition crop" (2500 stems/ha planted, pruned to 6 m, thinned at 20 m to 370 stems/ha) harvested at age 32 years. These were contrasted with the "new crop" (taken as the base regime, harvest age 26 years) and "farm forestry" (200 stems/ha stocking, high-quality site, harvest age 24 years). The results (Fig. 17) showed a clear trend of dramatic increases in the proportion of juvenile wood in all grades as felling age, silviculture, and site quality changed. Overall, the old crop was predicted to have approximately 17% juvenile wood, the transition crop 42%, the new crop 54%, and the farm forestry example 60%.

Variation in Juvenile Wood

Results from this exercise indicated that for a given felling age the proportion of juvenile wood would be strongly indicated by the log grade s.e.d. However, if the variation within grade is examined there remains a considerable unexplained range in the juvenile wood percentage. Distribution of juvenile wood percentage for the S3 grade is given in Fig. 18.

The range of juvenile wood percentage within all grades was quite considerable (e.g., S3 grade had a range of 40% to 80% for most felling ages). Further analysis indicated that logs within this grade s.e.d. specification (200–300 mm) could come from the lower portion of a small tree in the stand (and hence would have older wood) or from the top section of a large tree (with younger wood). This clearly indicates that the current log grading by s.e.d. may not adequately account for the wide variation in juvenile wood percentage encountered from logs within the same stand.

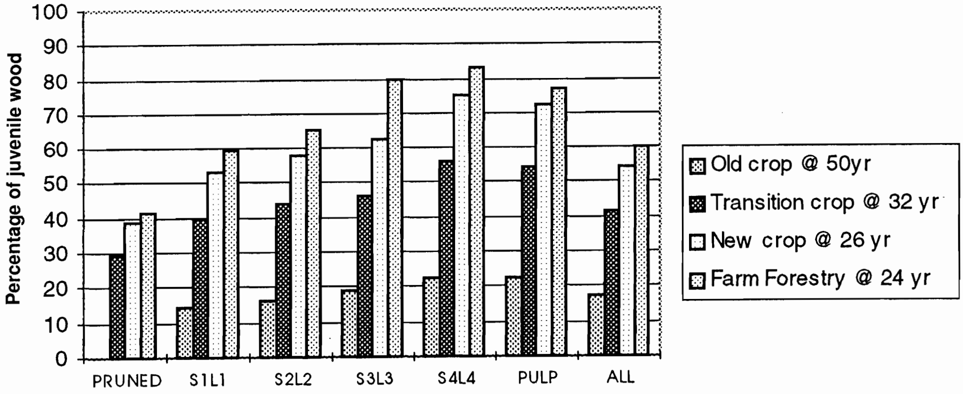

FIG. 17–Historic changes in the proportion of juvenile wood in central North Island forests.

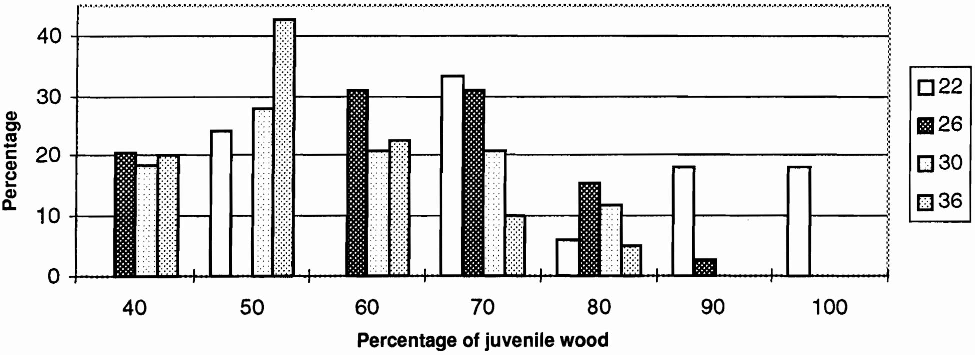

FIG. 18–Distribution of juvenile wood within S3 log grade by felling age.

Examination of correlations of juvenile wood with other log variables has indicated that Mean Log Age and rings/s.e.d. both give a better explanation of the proportion of juvenile wood within the log. Rings/s.e.d. is obviously a preferable measure as it can be easily assessed on the end of the log with little training. Logs with a considerable range in diameter and felling ages all fit the same relationship (Fig. 19); also, the proportion of juvenile wood may be best determined from a simple ring count on the small end of the log. There might be an opportunity to reduce the range of juvenile wood within-grade if logs were segregated by the number of rings in the small-end diameter—e.g., if logs with 15–20 rings/s.e.d. were segregated into a sub-grade (regardless of felling age) the proportion of juvenile wood they contained would fall within a 20% range (45%–65%).

Wood density in STANDPAK is determined by the user first selecting a density region within New Zealand (low, medium, or high); this level of density is then distributed by tree age and log height class. The relationship between rings/s.e.d. and mean log wood density (Fig. 20) indicates that STANDPAK predicts a wide range of wood density within a log grade and that there would be opportunity to reduce this range if logs within grades were segregated by the number of rings in the s.e.d.

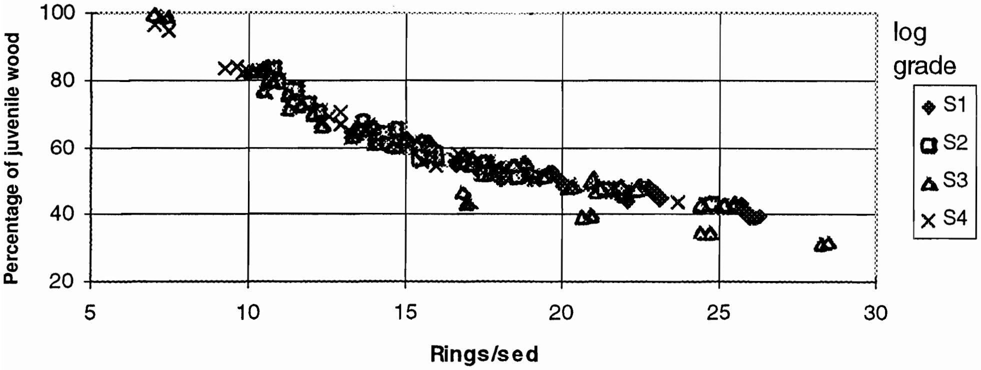

FIG. 19—Relationship between the proportion of juvenile wood and rings/s.e.d. for all S grade logs with felling ages 22, 26, 30, and 34 years.

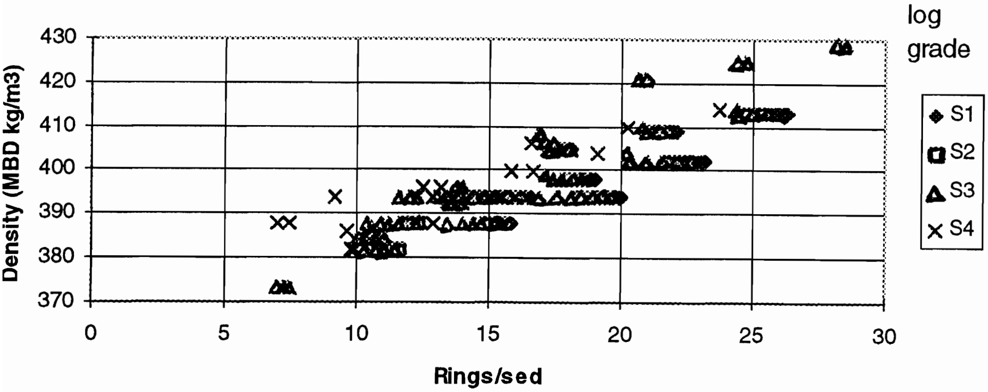

FIG. 20—Relationship between wood density and number of rings/s.e.d. for S grade logs with felling ages of 22, 26, 30, and 34 years. MBD = mean basic density.

Discussion

A modelling approach was used in this exercise in order to gain new insights into juvenile wood formation through the integration of numerous research results derived across a range of sites, treatments, and tree ages. From this approach new insights can be gained that might not be evident from the results of a single experiment. The complete integration within new modelling systems of site, genetics, and silvicultural effects on numerous wood quality variables will clearly be a major technical advancement.

Limitation of Results

The results given here are from new routines in STANDPAK and should be used with caution until extensive validation studies have been completed. Juvenile wood prediction relies on the accuracy of several models—viz basal area, height, and taper functions. For individual stands some error in prediction is expected in one or all of these functions. It is better to use these results in a comparative sense to give trends by treatments rather than to rely on them as absolutes.

Interactions

For the sake of clarity, only direct effects of single factors and groups of factors are reported here. Evidence of interaction effects (e.g., the influence of final-crop stocking appeared to be different on high- and low-quality sites) indicates that the results described here should not be generalised—results for one stand cannot be assumed to apply to others.

Methods of Reducing Juvenile Wood

An obvious question to be addressed by forest managers concerns the reasonable steps that can be taken to reduce the proportion of juvenile wood being grown in *P. radiata* stands. From the results of this study it appears that some options are likely to be more effective than others. Clearly, felling age is a major factor that can be altered if wood flows and economic considerations allow. Severe pruning and late thinning would also have a small impact on reducing juvenile wood.

Efforts by tree breeders to rate the juvenile wood quality of *P. radiata* parents will be greatly expanded in a new research project at the New Zealand Forest Research Institute (Sorensson & Vincent 1997). It is intended that new information about juvenile wood quality developed in this project will be made available to buyers of tree stocks through the GF Plus scheme (Vincent 1997).

Wood processors buying logs graded only by s.e.d. gain little indication of the proportion of juvenile wood contained within an individual log, i.e., within a grade or small-end diameter class there is a wide range in juvenile wood percentage and wood density. However, a log grading system that segregates by s.e.d. ***and*** a simple ring count should substantially improve the definition of the proportion of juvenile wood and the wood density within a log.

Considerably more research is obviously needed on this proposal before it could be implemented. The interactions with site and the practicalities of implementing such a change are some of the issues that will be investigated and further developed with the forest industry.

Economic Considerations

Forest management regimes generally involve numerous trade-offs and interactions. Options for minimising juvenile wood should not be considered in isolation. Changes in silvicultural regime may influence log small-end diameter, clearwood depth (or PLI), and branch size, which may affect log value and hence forest profitability. Financial considerations such as discount rate and cash flow will also influence decisions on silvicultural regimes and felling age.

Minimising juvenile wood with slower tree growth or longer rotations is likely to increase growing costs, but log price gradients that are influenced by the proportion of juvenile wood wouldl help offset this.

CONCLUSIONS

From this study it was concluded that felling age has a major influence on Mean Log Age and the proportion of juvenile wood. Older stands were indicated to have less juvenile wood in all the log grades tested. Genetic development could have a major influence on the proportion of juvenile wood if the expression of juvenile wood characteristics can be contained within fewer rings. GF rating, as it affects growth rate, has little effect on the proportion of juvenile wood. Site quality has a major influence on the proportion of juvenile wood, with low-quality sites producing much less juvenile wood than medium- or high-quality sites. Silvicultural treatments involving pruning, timing of thinning, and tree stocking have little influence on the proportion of juvenile wood.

Changes in regime, felling age, and site quality of forests in the central North Island indicate that dramatic increases in the proportion of juvenile wood may have occurred and may explain current concerns about wood quality.

A key consideration in the processing of the current crop of *P. radiata* is the adequate segregation of the wide range in log quality. If Mean Log Age or the number of rings/s.e.d. is added to the current system of log grades (which use s.e.d.), the proportion of juvenile wood in each log and the variation in wood density would be better estimated. Any inherent price/age or price/quality gradient could then be recognised by the market. If such an amendment to log grades were adopted, the wood processing industry would be better positioned to cope with the variation in juvenile wood percentage and Mean Log Age than at present.

Revision of forest management practices aimed at minimising juvenile wood should be examined within an economic framework so that the costs and benefits of growing higher quality wood are included in the analysis.

The new functions within STANDPAK v6.2 that predict Mean Log Age and juvenile wood should be helpful to both forest growers and wood processors in evaluating and understanding the influence of site, genetics, and silviculture on wood quality.

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