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Technical Note

Application of a wood-properties-based, techno-economic model in assessing the effects of stand density and seedlot on stumpage value in two *Pinus radiata* silviculture-breeds trials.

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Summary: Economic return at end-of- rotation reflects a composite of stand productivity and favourable stem properties, both external and internal. Poor market signals, in terms of price, for wood with superior properties, and poor understanding of segregation costs across the value chain can make it difficult to value logs based on internal as well as external properties. SEGMOD, a techno-economic model which determines mill door return-to-log (RTL) values and then subtracts harvesting, transport and inventory costs to arrive at stumpage (RTL) values, was used to assess the effects of stand density, seedlot and wood stiffness in two silviculture-breeds trials. We found that there were large and significant differences in merchantable volume and stumpage value among seedlots and different levels of post-thinning stand density. Merchantable volume and stumpage value, in unpruned or low-pruned stands, were both maximized at a residual stand density of 600 stems ha^{-1}. Pruning to 6 m and thinning to lower residual stand densities would not be expected to alter this finding. Wood stiffness was found to be positively affected by stand density and to differ among seedlots. The highest stiffness seedlots were not associated with the highest stumpage values. Other stem features, such as forking or larger branches, may have negatively affected stumpage value in the highest stiffness seedlots.

Introduction

The radiata pine tree improvement programme in New Zealand dates back to the 1950s when the first plus tree selections were made [1, 2, 3]. The original goal of the breeding programme was the production of genotypes with rapid growth, straight stems, small branches and good branching habit.

The silviculture-breeds trials, established between 1987 and 1991 at 28 locations throughout New Zealand, contain seedlots with different levels of genetic improvement for growth and stem form. Because these seedlots are planted on a range of sites, at a range of stand densities, it is also possible to test whether there are seedlot by stand density interactions.

Understanding the variation in wood properties that exist within and between trees in a stand, and between stands is important for both growers and wood processors [4]. The silviculture-breeds trials provide an opportunity to assess the extent to which this variation in wood properties is controlled by site, silviculture and genetics.

Long-term research trials such as the silviculture breeds series also provide the opportunity to quantify the effects of site factors, seedlot and stand density on economic returns at harvest. Economic return at end of rotation reflects a composite of stand productivity and the proportion of favourable external and internal stem properties. An approach for quantifying the impact of genetic improvement on site productivity and diameter growth on forest value has been applied to data from the silviculture breeds trials and other large-plot genetic gains trials in New

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Zealand [5]. However, the additional economic value from improvements in stem form and branching characteristics was not examined [6]. Most recently, the contribution that improvements in stem form and branching have on standing value was calculated for a subset of silviculture-breeds trials based on pre-harvest assessment data [6, 7].

While differences in internal wood properties exist among trees from different seedlots and levels of stand density, realising additional value depends on the ability to identify these differences and segregate material into different grades. However, a review of tools and techniques for segregating wood based on internal properties, such as wood density and stiffness, concluded that the benefits of using these tools and techniques are not clear due to poor market signals (in terms of price) for wood with superior properties, and poor understanding of costs across the value chain [8].

This Technical Note describes SEGMOD, a wood-properties-based, techno-economic model [9] and how it has been applied in two silviculture-breeds trials to analyse the effects of stand density and seedlot on product yields and relative stumpage value. It then presents the results of the analyses.

Method

Description of SEGMOD

SEGMOD was developed to determine if the benefits of segregating stands and logs based on internal wood properties outweighed the additional costs required to collect and use this information. It includes the ability to optimally segregate and value logs based on internal wood properties. It calculates "stumpage" and mill door return-to-log (RTL) values per hectare based on user-selected wood properties, segregation approaches, and terrain conditions. Five different segregation approaches can be evaluated: (1) no segregation (*NoSeg*); (2) segregation in the forest based on pre-harvest inventory data (*PHISeg*); (3) segregation at the landing (*LandSeg*); (4) segregation at a centralised processing yard (*CPYSeg*); and (5) segregation in a mill (*MillSeg*). Under a no segregation approach, segregation is only based on size and external quality features and the optimal bucking routine will ignore internal wood properties. If segregation is based on size and external characteristics plus internal quality, then the user can segregate appearance grade logs based on the amount of clear wood (as quantified by the Pruned Log Index [10] and/or resin score [11] and for structural grade logs based on acoustic velocity and/or wood density. SEGMOD is able to accommodate four different end-products: (1) appearance lumber; (2) structural lumber; (3) medium density fibreboard (MDF); and (4) export logs.

The starting point for the model is user-supplied stand data consisting of descriptions of the external stem characteristics and internal wood properties (density and acoustic velocity) for a representative sample of trees. Tree external descriptions are based on a system of overlapping feature codes, similar to those used in systems such as YTGEN. Internal wood properties information can be provided by the user based on field sampling or predicted from site-specific environmental variables [12, 13]. The two internal wood properties of most interest are density and modulus of elasticity (often approximated through acoustic wave velocity) as these affect the outturn of structural lumber. Values measured (or predicted) at breast height (1.4 m) are then extrapolated to other heights in the stem using non-linear functions that have been developed for wood density and acoustic velocity. These stem descriptions are consistent with log specifications, which are provided in terms of minimum and maximum values of small-end diameter, length, acoustic velocity and density. Limits are also specified for maximum branch size, defect core size, internode index and resin score. The number of log grades (sorts) can be varied by segregation approach. These descriptions enable stems to be optimally bucked and both mill-door return-to-log values (RTL) and log grade recovery from stands to be calculated.

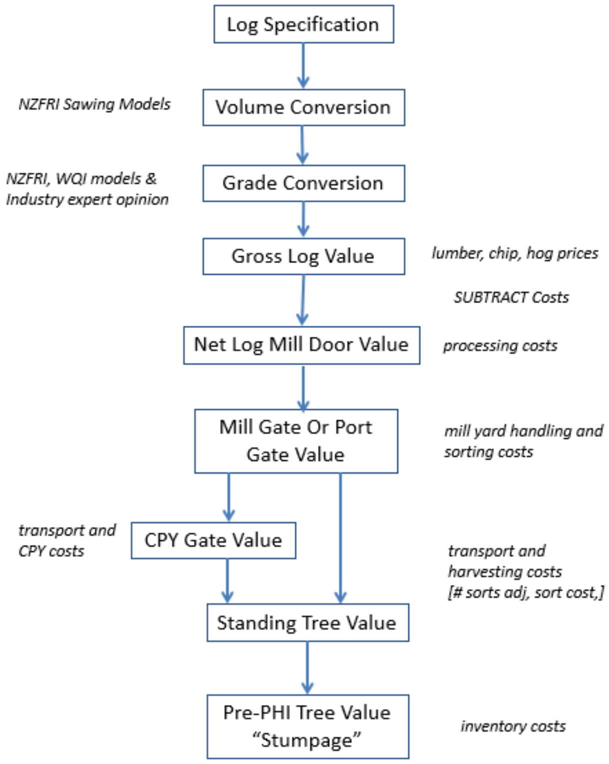

Figure 1. Schematic representation of the process for calculating mill-door and stumpage return to log values in SEGMOD**.**

SEGMOD first calculates a mill door RTL value ($ per m^3) for each log type included in the log specification file (see Figure 1). These RTL calculations are based on user-provided prices and processing costs for lumber (appearance and structural grades), MDF, chip, hogfuel and export logs, along with appropriate volume and grade recovery factors. The recovery factors are based on sawing and grading studies undertaken by NZFRI [14] and WQI (unpublished data) (e.g. see Figures 2 and 3). The relevant mill yard, transport, CPY, harvesting and inventory costs are subtracted from the mill door RTL to derive relative "stumpage" RTL values for each log type.

Logs are then optimally allocated from each stem to appearance grade, structural grade, fibre, and export log markets using dynamic programming, optimal log bucking routines with the objective of maximizing total "stumpage" RTL value per hectare for unconstrained log supply markets.

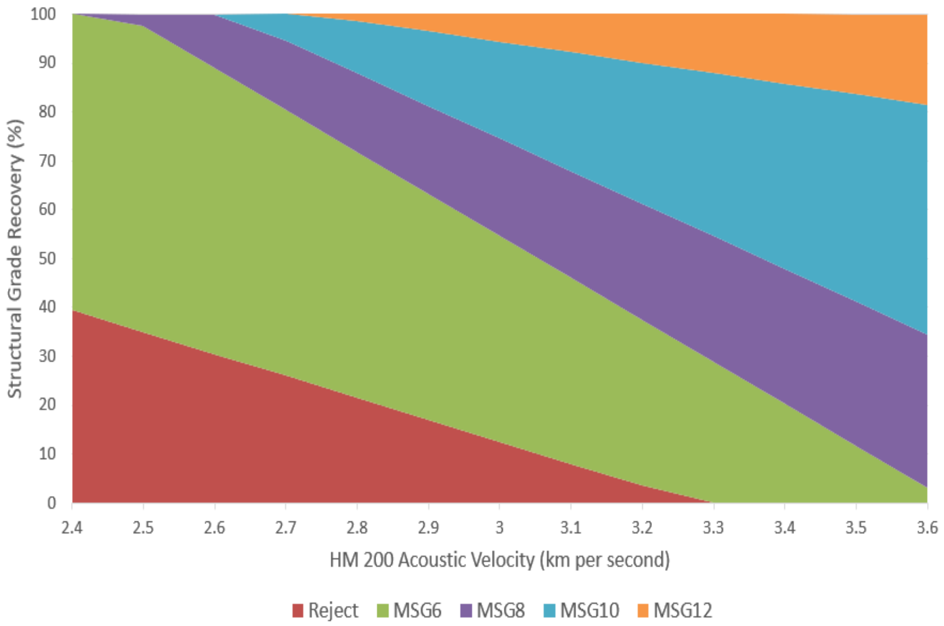

Figure 2. Example showing the predicted structural grade recoveries as a function of resonance acoustic velocity measured with a portable HM200 tool (Fibre-gen, Christchurch). (Adapted from WQI Ltd. unpublished data).

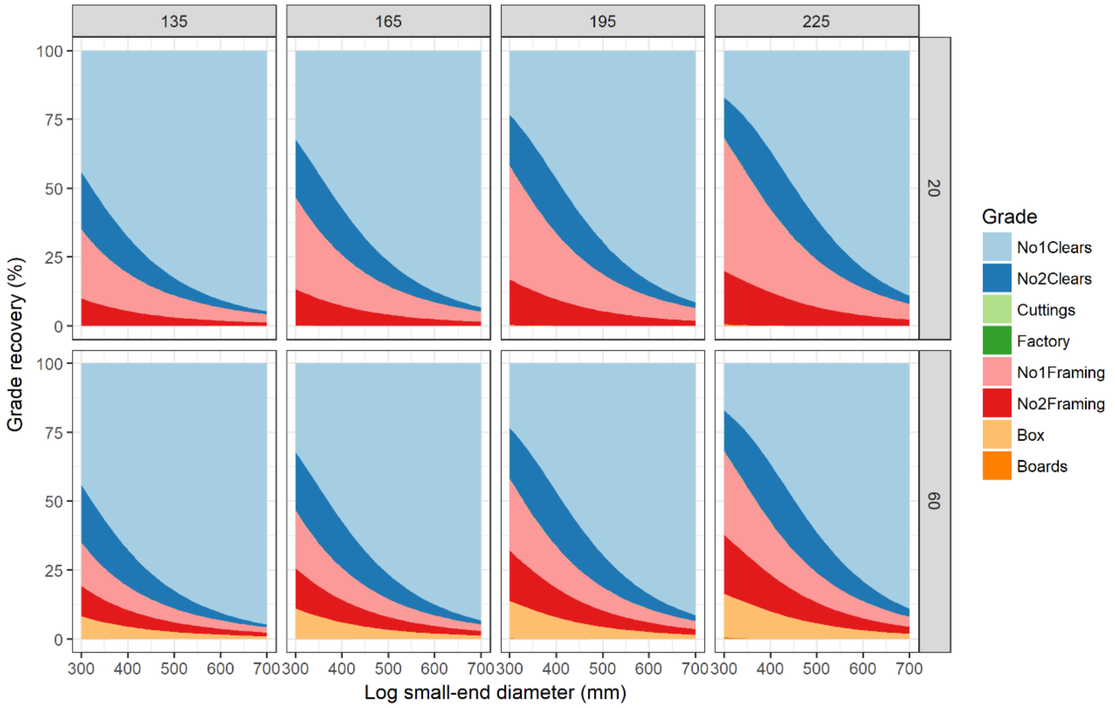

Figure 3. Example showing the predicted grade recoveries from the pruned log models as a function of log small-end diameter for four different defect core sizes (135, 165, 195 and 225 mm) and two different maximum branch sizes (20 and 60 mm)

Description of the silviculture-breeds trials
The silviculture-breeds trials were established between 1987 and 1991 at 28 locations around New Zealand. End-of-rotation assessments carried out at two of these trials are used in this Technical Note:

FR10, located in Glengarry Forest ~ 35 km northwest of Napier, and FR121/2, located in Atiamuri Forest ~ 40 km southwest of Rotorua.

The core experimental design of the Glengarry trial consisted of six silvicultural treatments applied to each of four seedlots. Initial planting densities ranged between 250 and 1500 stems ha^{-1} and residual stand densities after thinning ranged between 100 and 600 stems ha^{-1}. In five of the treatments, trees were low pruned to ~ 2.2 m. In the sixth treatment, trees were not thinned or pruned. Seedlot genetic ratings ranged between GF7 and GF21.

The Atiamuri trial had a different experimental design. There were seven silvicultural regimes comprising different, un-replicated combinations of initial stand density (250 to 1000 stems ha^{-1}) and post-thinning stand density (100 to 1000 stems ha^{-1}) and pruning treatments (pruned or not pruned). Seedlot genetic ratings ranged between GF7 and GF25. Only three seedlots were applied to all seven silvicultural regimes.

The trials were assessed prior to harvesting, at age 28 years for the Glengarry trial and at age 24 years for the Atiamuri trial [6]. DBH was recorded for all trees and total tree height was recorded for up to 13 suitable trees in each plot. The standard approach for timber cruising in New Zealand was used to describe external features of each stem [15].

Internal wood properties measurements were made on every height tree within a plot. An outerwood density core was collected at breast height and basic density (kg m^{-3}) determined. Basic density was not used in our analyses, however. Wood stiffness was estimated based on acoustic velocity measurements, collected near breast height on each tree using an ST-300 tool (Fibre-gen, Christchurch). Trees not assessed for acoustic velocity were allocated an acoustic velocity from a normal distribution for the plot. Breast height ST-300 acoustic velocities were used to calculate breast height HM-200 acoustic velocity which were then used to predict HM-200 acoustic velocity profiles up each tree.

Assessment of effects of stand density and seedlot

For both the Glengarry and Atiamuri trials the same set of assumptions were used when running SEGMOD. It was assumed that the terrain was steep and segregation based on acoustic velocity was carried out on landings in the forest using either a processor with an acoustic tool on a harvester head (e.g. PH330 by Fibre-gen) or a hand-held tool (e.g. HM200 by Fibre-gen) [16]. Distances from the trial locations to Appearance, Structural, and Fibre mills, and an Export port were assumed to be 54, 92, 80, and 91 km, respectively. Log specifications were as shown in Appendix A1. Product prices for lumber, MDF, chip, hogfuel, and export grade logs were as shown in Appendix A2.

Not all treatment combinations from the two trials were included in the analyses. Only treatments with residual stand densities after thinning of 200, 400, or 600 stems ha^{-1} were included. Table 1. provides a summary of the treatments for the 48 plots included in the analyses along with the mean acoustic velocities for each treatment. GF21- and GF25-rated seedlots were combined in the analyses and are reported as GF21+.

Table 1. Summary of the seedlot/stand density treatments included in the analyses along with the mean acoustic velocities for each treatment.

Residual stand density (stems ha^{-1})	Seedlot number* and GF rating	Number of plots	ST300 Acoustic Velocity (km s^{-1})
200	FRI179/2320 (GF7)	6	4.38
	9/3/86/166 89/15 (GF13)	6	4.48
	3/3/8501 88/105 (GF14)	5	4.33
	6/3/86/46 89/708 (GF21+)	6	4.38
400	GF7	4	4.46
	GF13	4	4.51
	GF14	2	4.51
	GF21+	4	4.47
600	GF7	3	4.62
	GF13	3	4.68
	GF14	2	4.61
	GF21+	3	4.55

*Seedlots were the same across each level of stand density so are only listed once

Two sets of stumpage values were calculated for each plot; the first (AS CRUISED) was based on actual cruise information with respect to pruning (i.e. trees were either low pruned or unpruned) and the second (PRUNED) was based on the assumption that each of the residual trees in the 200 and 400 stand density treatments was pruned to 6 m and their heights and DBHs reduced by 1 m and 5 cm, respectively [17].

Results

A total of 1400 trees in 48 plots were assessed for external stem features. Acoustic velocity was measured on 552 trees and assigned, based on fitted normal distributions from each plot, to the remaining 848 trees.

There was a strong influence of residual stand density on merchantable volume, with volume increasing as stand density increased. Note that in some case, similar volumes were obtained at nominal densities of 400 stem ha^{-1} as were obtained at 600 stem ha^{-1}. There were significant differences among seedlots, but no interaction between seedlot GF rating and stand density. For a given stand density, GF14 and GF21+ rated seedlots had higher merchantable volumes than the GF7 or GF13 rated seedlots.

Within plots, the coefficient of variation in acoustic velocity among trees ranged between 2.6% and 10.1%. There were small, but statistically significant, differences in acoustic velocity:

- between sites - the 28-year-old Glengarrry stand having higher velocities (~6%) on average than the 24-year-old Atiamuri stand,
- among stand densities. Plots with stand densities of 400 and 600 stems ha^{-1} had 2% and 5% higher acoustic velocities, respectively, than did plots with stand densities of 200 stems ha^{-1}.
- among seedlots. Plots with seedlots with a rating of GF13 had significantly higher acoustic velocities (~2%) than plots containing seedlots with GF7, GF14 and GF21+ ratings. The seedlot with a rating of GF14 had the lowest acoustic velocity.

AS CRUISED stumpage values increased as residual stand density increased for both trials (Figure 4). There were significant differences among seedlots for AS CRUISED stumpage values. There was no interaction, however, between seedlot GF rating and stand density. Once site was accounted for, GF14 and GF21+ rated seedlots had higher stumpage values than the GF7 (Climbing Select) seedlots. The highest stumpage values were in the GF14 seedlot treatments and the lowest in the GF13 (long internode) seedlots.

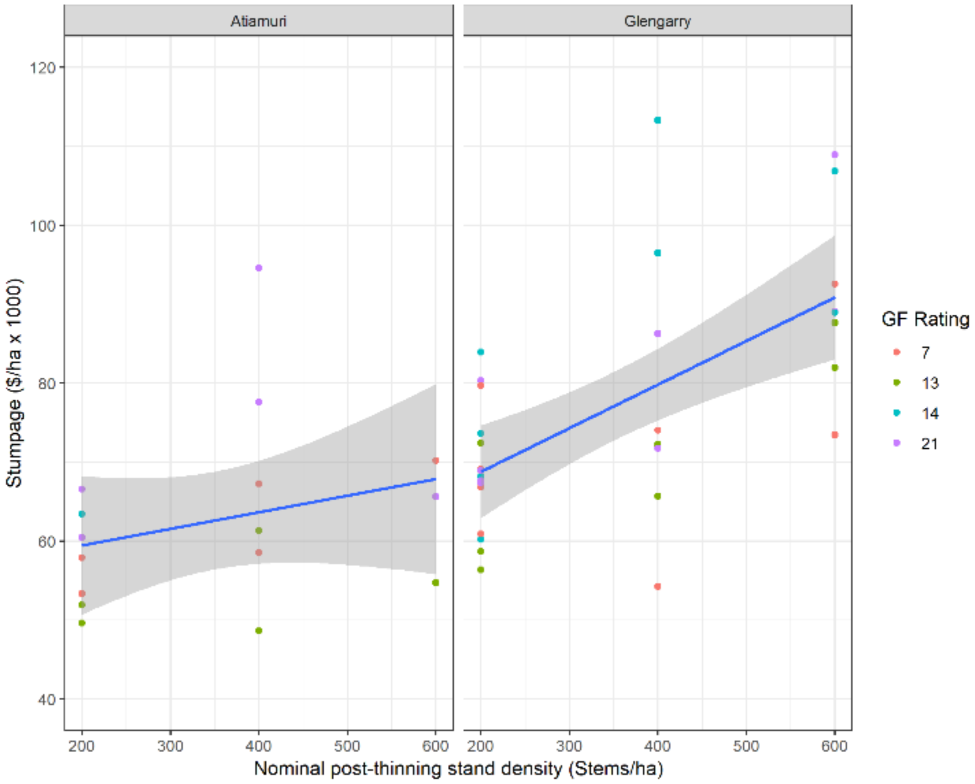

Figure 4. Plots of stumpage value (AS CRUISED) versus residual stand density for four seedlot groupings (GF7, GF13, GF14 and GF21/GF25) for the Atiamuri and Glengarry silviculture-breeds trials.

PRUNED stumpage values for both trials also increased as residual stand density increased (Figure 5). It should be reiterated that only trees in the 200 and 400 stems ha^{-1} stand densities shown in Figure 5 were assumed to have been pruned to 6 m; the 600 stems ha^{-1} treatment were AS CRUISED. The difference between the 200 and 400 stems ha^{-1} treatments were less apparent, particularly at Glengarry. However, the 600 stems ha^{-1} plots still yielded higher stumpage returns, despite not being pruned to 6 m. The higher value from pruned logs in the lower stand density treatments is more than offset by the lower merchantable volume in these treatments. There were significant differences among seedlots. Seedlots with GF14 and GF21+ ratings had higher stumpage values than those with GF7 and GF13 ratings. Seedlots with a GF 14 rating had the highest stumpage values and those with a GF13 rating (i.e. long internode) the lowest.

Residual stand density had a small negative effect on the volume allocation of logs to structural grades (e.g. mean = 57.2%, SD = 8.8% for 200 stems ha^{-1} and mean = 49.9%, SD = 12.2% for 600 stems ha^{-1}) and no effect on the allocation of logs to export markets. GF13 rated seedlots had a lower allocation of volume to structural logs and a higher allocation to export logs. GF14 rated seedlots had a higher allocation of volume to structural logs and a lower allocation to export logs.

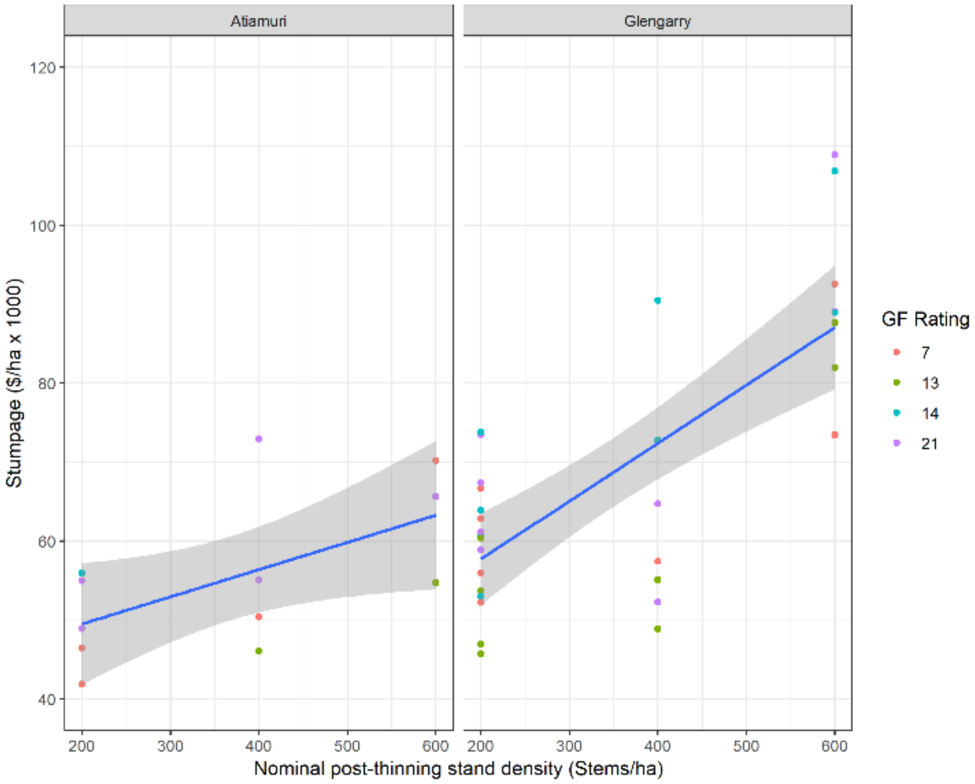

Figure 5. Plots of stumpage value (PRUNED) versus residual stand density for four seedlot groupings (GF7, GF13, GF14 and GF21/GF25) for the Atiamuri and Glengarry silviculture-breeds trials. Note that the 600 stems ha^{-1} treatment were NOT assumed to be pruned to 6 m and so the stumpage values are the same as those for the AS CRUISED analysis.

Discussion

Results from the Atiamuri and Glengarry trials show that merchantable volume is affected by seedlot and is maximised at a residual stand density after thinning of 600 stems ha^{-1}. Other assessments, where trees were grown from their measurement age to age 28, of these two trials [6] and of six additional trials within the silviculture-breeds series [7] also found that merchantable volume is maximised at a residual stand density of 600 stems ha^{-1}. In a recent study [18], where a growth and yield simulator was used to predict volumes at age 28 for an unpruned structural regime, it was also found that yield was maximised at ~ 600 stems ha^{-1}.

Stumpage value followed the same trends as merchantable volume, being highest with a residual stand density of 600 stems ha^{-1} and being greater with higher GF rating seedlots (GF14 and GF21+) than lower GF rating seedlots (GF 7 and GF13). Other assessments, based on total value prior to subtraction of harvesting and transport costs, have found similar results with respect to residual stand density and seedlots [6, 7]. It should be noted that the two sites were quite similar and analysis indicated that site factors had no significant effect on stumpage value. Further assessments of a greater range of sites in the silviculture breeds trials showed, however, that site does have a highly significant impact on economic returns [7].

Our analyses also showed that both seedlot and residual stand density had a significant and positive effect on acoustic velocity. Earlier studies in younger stands, including mid rotation assessments of the trials in the silviculture-breed series, also found that acoustic velocity increased with increasing stand densities [19, 20]. Contrary to expectations [18], however, we found that better internal wood properties in the form of high acoustic velocities, did not lead to the highest stumpage values. In our study, the highest stumpage values were associated with the GF rating having the lowest mean acoustic velocity (GF14). Conversely, the lowest stumpage values were associated with the GF rating having the highest mean acoustic velocities. The genetic gains in merchantable volume outweighed the gains in acoustic velocity. It should be stressed that acoustic velocity variation between seedlots was not high in the Atiamuri and Glengarry trials, and selection of genetic material was not based on internal wood properties when the silviculture-breeds trial series was established.

Pruning of stems up to 6 m and thinning to residual stand densities of 200 or 400 stems ha^{-1} produced lower stumpage values than not pruning to 6 m and thinning to a residual stand density of 600 stems ha^{-1}. The lower stumpage values at the lower residual stand densities in the PRUNED analyses was partly due to the assumed reduction in merchantable volume associated with pruning of stems. Part would also have been due to significantly higher large branching proportions in the 200 and 400 stems ha^{-1}

treatments than in the 600 stems ha^{-1} treatments [14] in the Atiamuri and Glengarry trials.

Conclusions

Based on the end-of-rotation assessment of the Atiamuri and Glengarry trials, we found that there were large and significant differences in merchantable volume and stumpage value between seedlots and the levels of residual stand density examined. When averaged across all stand densities, the best seedlots had a stumpage value that was ~ \$20,000 ha^{-1} greater than the poorest performing seedlot. Merchantable volume and stumpage value were both maximized at a residual stand density of 600 stems ha^{-1}. Pruning to 6 m and thinning to lower residual stand densities would not be expected to alter this finding. Finally, wood stiffness was found to be positively affected by stand density and to differ among seedlots. High stiffness seedlots were not necessarily associated with high stumpage values, however. Other stem characteristics, e.g. forking or larger branches may have masked the benefits of higher stiffness wood.

Acknowledgements

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Appendix 1

Table A1: The log grade specifications used in the yield and relative "stumpage" analyses.

Market type	Length (m)	SED (cm)	Max Knot (cm)	Max Sweep (mm/m)	HM200 Acoustic velocity (km s^{-1})	Max Resin Class	Other
Appearance	5.1	40	0	30	NA	1	
Appearance	5.1	40	0	30	NA	2	
Appearance	5.5	30	7	25	NA	1	Spike knot < 6 cm
Appearance	5.5	20	7	25	NA	1	Spike knot < 6 cm
Appearance	5.5	20	7	25	NA	2	Spike knot < 6 cm
Appearance	4.9	40	10	25	NA	1	Spike knot < 6 cm
Appearance	4.9	30	10	25	NA	1	Spike knot < 6 cm
Appearance	4.9	30	10	25	NA	2	Spike knot < 6 cm
Structural	6.1	30	10	25	3.0-3.4	NA	Spike knot < 10 cm
Structural	6.1	30	10	25	2.6-3.0	NA	Spike knot < 10 cm
Structural	5.5	40	10	25	3.0-3.4	NA	Spike knot < 10 cm
Structural	5.5	30	10	25	> 3.4	NA	Spike knot < 10 cm
Structural	5.5	30	10	25	2.6-3.0	NA	Spike knot < 10 cm
Structural	4.9	30	10	25	3.0-3.4	NA	Spike knot < 10 cm
Structural	4.9	30	10	25	2.6-3.0	NA	Spike knot < 10 cm
Fibre	2.7	10	20	100	NA	NA	No rot, crutch, excessive kinks or sweep
Export	5.1	40	0	30	NA	1	
Export	5.8	30	10	30	NA	NA	Spike knot < 10 cm
Export	4.0	30	10	30	NA	NA	Spike knot < 10 cm
Export	3.8	26	25	30	NA	NA	No rot, crutch, excessive kinks
Export	3.8	25	10	25	NA	NA	Spike knot < 10 cm
Export	3.8	12	10	100	NA	NA	Spike knot < 10 cm

Table A2: Product prices used in the yield and relative “stumpage” analyses.

Product	Price ($\$/m^3$)
Lumber - #1 Clears	775
Lumber - #2 Clears	665
Lumber - Cuttings	325
Lumber - Factory	265
Lumber - #1 Framing	525
Lumber - #2 Framing	375
Lumber - Box	430
Lumber - Board	265
Lumber – MSG12	625
Lumber – MSG10	595
Lumber – MSG8	545
Lumber – MSG6	400
Lumber – MSG<6	335
MDF	350
Chip - solid wood equivalent	50
Hogfuel – solid wood equivalent	10
Pruned Export Logs	170
A Export Logs	135
KI Export Logs	128
K Export Logs	122
KIS Export Logs	112