Growing confidence in forestry's future Research Programme

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Technical Note

Effects of silviculture and seedlot on radiata pine growth, wood properties and end-product quality

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Summary: A series of trials was established between 1987 and 1991 to enable the effects of site, seedlot and silviculture on growth and wood properties of radiata pine to be quantified. These trials are reaching maturity and most will be harvested during the Growing Confidence in Forestry's Future research programme. This note provides an overview of this unique trial series. It also presents the initial results from the end-of-rotation assessment of the trial that was established at Atiamuri Forest, which contained five seedlots with GF ratings ranging from GF7 to GF25 and residual stand densities after thinning ranging from 100 stems ha^{-1} to 600 stems ha^{-1}. There was also an un-thinned treatment that was established at a density of 1000 stems ha^{-1}. Results from the end-of-rotation assessment showed that both volume and gross value were maximised for the GF25 seedlot growing in the plot that was thinned to a residual stand density of 400 stems ha^{-1}. Wood density and stiffness (as assessed by the HM200 tool) both increased with increasing stand density. The outerwood basic density of the GF25-rated seedlot was 17 kg m^{-3} lower than that of the GF7 seedlot, but wood stiffness was similar across all seedlots. These results have confirmed the trends that were observed in earlier mid-rotation assessments of a subset of the silviculture-breeds trials. More in-depth assessment of the wood properties from the trial is ongoing, with the aim of quantifying the impacts on end product quality. Additional trials in this series will be assessed as they reach maturity. These data will also be useful in quantifying realised genetic gain for growth and wood density.

Introduction

The wood that will be harvested over the next 15 years is already in the ground and for the most part is growing in stands that have received all their silvicultural treatments. The silvicultural history of these stands, along with their location and the choice of tree stocks, will affect the wood properties of the trees in them. Understanding the variation in wood properties that exists within and between trees in a stand, between stands, and the extent to which this variation is controlled by site, silvicultural and genetics, is important for both growers and wood processors. Some of these factors, such as the choice of genetic material and tree spacing, can be manipulated by silviculturalists to achieve desired wood quality outcomes.

There has been a considerable amount of research into the drivers of wood quality in radiata pine. Some of this early work focused on understanding the variation in wood density across New Zealand [1, 2], and the effects of thinning and fertilisation treatments on wood density [3-5], including widely-spaced agroforestry stands[6]. More recent studies have synthesised much of this earlier knowledge and have used it to develop wood density models [7, 8]. Wood properties other than density have also been assessed. In particular, the development of SilviScan and portable acoustic tools have enabled microfibril angle and modulus of elasticity to be assessed on relatively large numbers of trees, and several studies have investigated how these properties are affected by factors such as stand density [9-15].

Understanding the impacts of site, silviculture and genetics on end product quality, as well as various wood properties, is important. Historically, the connection between forest management and end-product quality has been quantified through undertaking sawing studies and developing simulation models. Much of this work was done as part of the Conversion Planning Project [16]. However, newer approaches to link end-product quality to forest management were developed under the

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Radiata Management theme of Future Forests Research. In particular, the PQSim model enables the stiffness and distortion of boards to be simulated using information on the intra-stem patterns of wood density, microfibril angle, spiral grain angle and wood chemistry. Within the Growing Confidence in Forestry's Future (GCFF) programme, this approach will be used to predict the impacts of site, silviculture and genetics on end-product quality using data from replicated trials.

A series of trials was established between 1987 and 1991 at 28 locations throughout New Zealand to compare the performance of genetically improved breeds when grown at a range of stocking levels. Some of these trials no longer exist due to factors such as establishment failure, wind damage or land-use conversion, but the remainder are expected to be harvested within the GCFF programme. This Technical Note describes the end-of-rotation assessments that are planned for these trials, and presents some preliminary results from the 1990 silviculture-breeds trial at Atiamuri Forest that was harvested in early 2015 when it was 24 years of age.

Methods

Design of the silviculture-breeds trials

Of the 28 silviculture-breeds trials that were established between 1987 and 1991, 22 are still standing (Figure 1).

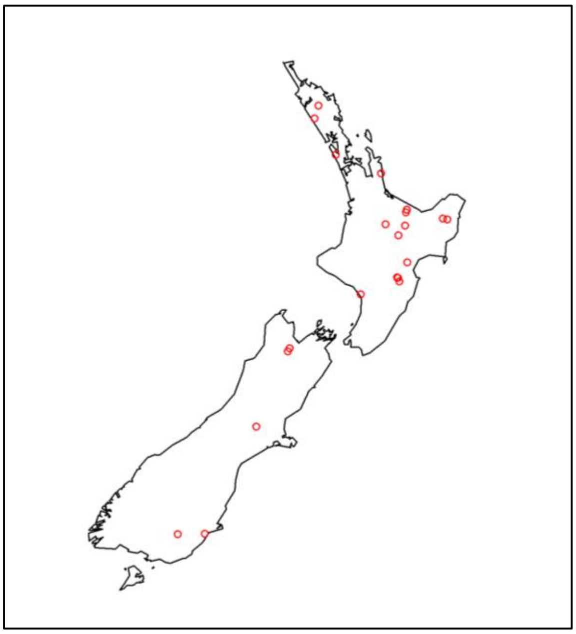

Figure 1: Location of 22 remaining silviculture-breeds trials established between 1987 and 1991.

The core experimental design of the 1987 trials consisted of six silvicultural treatments carried out on each of four seedlots [17]. Initial planting densities ranged from 250 stems ha^{-1} up to 1,500 stems ha^{-1}, and stands were thinned to residual stand densities ranging from 100 to 600 stems ha^{-1}. In five of the silvicultural treatments, trees were pruned when the mean tree height was 6.2 m, to leave approximately 4 m of green crown remaining. In the sixth silvicultural treatment the stand was established at an initial density of 500 stems ha^{-1} and was not thinned or pruned. The GF rating of the four seedlots ranged from GF7 up to GF21, and included a long-internode seedlot with a rating of GF13. At each installation, all combinations of seedlot and silvicultural regime were replicated twice.

An additional four trials were planted in 1988. These had broadly similar silvicultural treatments to the 1987 installations, but with different seedlots. The GF ratings ranged from GF9 up to GF22 but varied somewhat between trials. The series planted the following year (1989) contained three or four silvicultural treatments, typically applied to four seedlots. The silvicultural regimes consisted of initial stand densities ranging from 500 to 833 stems ha^{-1} and post-thinning stand densities ranging from 200 to 667 stems ha^{-1}. At each trial site, there was one regime that did not involve thinning or pruning. GF ratings ranged from GF2 to GF25 at each trial, except at one where the highest rating was GF23. Six different seedlots were tested in one trial. Each seedlot by silvicultural regime combination was replicated twice.

The 1990 and 1991 silvicultural-breeds trials had a different experimental design. These trials contained selected combinations of silvicultural regime and seedlot and were un-replicated. There were seven silvicultural regimes, comprising different combinations of initial stand density (250, 500 and 1000 stems ha^{-1}) and post-thinning stand density (100, 200, 400, 600 and 1000 stems ha^{-1}) and pruning treatments (pruned and un-pruned). Five seedlots were included, ranging in GF rating from either GF6 or GF7 to GF25. This included a long-internode GF13 seedlot. All seven silvicultural regimes were applied only to the GF6 or GF7, GF25 and GF13 seedlots.

Growth and wood properties assessment

The first end-of-rotation assessment of a silviculture-breeds trial was carried out at FR121/2 – a 1990 trial located at Atiamuri. The diameter at breast height (dbh) was measured on all live trees in each plot before the stand was felled. The total height was measured on a sub-sample of trees (typically 12) in each plot. An outerwood density core and a pith-to-bark density core were taken on these same trees. The acoustic velocity was also measured using the ST-300 tool (Fibre-gen, New Zealand). Each plot was also measured using the forest manager's standard pre-harvest inventory prescription. This included the assessment of tree dimensions and an overlapping feature cruise of plot trees. These were used to provide estimates of merchantable volume by log grade, and the total value of each plot (using current indicative log prices[1]) was extracted.

After the trees were felled, they were cross-cut at a top diameter of 10 cm, and the acoustic velocity of the stem was measured with an HM-200 tool (Fibre-gen, New Zealand). Cross-sectional discs were then collected at 5-m intervals up the stem (Figure 2). These discs will be assessed using Scion's new wood properties scanner (DiscBot), which is able to measure density, microfibril, spiral grain angle and wood chemistry on discs. The variation in these properties within a tree stem is a major driver of sawn timber performance – particularly stiffness and distortion.

Figure 2: Stacks of wood discs that have been cut from individual trees. These discs will be scanned and the wood properties mapped.

Results

Stand development differed substantially between treatments (Figure 3). As expected, the un-thinned plots established at 1000 stems ha^{-1} had experienced considerable mortality and were standing at close to the maximum carrying capacity of the site. In contrast, the stands thinned to a residual density of 250 stems/ha had only just reached the lower limit of full site occupancy (55% of the maximum size-density line) at age 24 years. The 100-stems ha^{-1} plots were not measured after 1999, so relative site occupancy shown in Figure 3 is artificially low.

The mean dbh at age 24 years was strongly affected by stand density. It ranged from 65.9 cm in the plots thinned to 100 stems ha^{-1} down to 43.6 cm in the un-thinned plots established at a density of 1000 stems ha^{-1}. The maximum total standing volume of 1042 m^3 ha^{-1} was produced by the GF25 rated seedlot in the unpruned regime thinned to 400 stems ha^{-1} (Figure 4). This corresponded to a mean annual increment (MAI) of approximately 43 m^3 ha^{-1} yr^{-1}. Conversely, the lowest volume (601 m^3 ha^{-1}) was produced by the GF7 rated seedlot in the pruned regime thinned to 200 stems/ha. This corresponded to an MAI of approximately 25 m^3 ha^{-1} yr^{-1}. The un-thinned treatments that were established at 1000 stems ha^{-1} had reached their maximum MAI for volume growth at between 15 and 20 years, hence total volume was less than in the plots thinned to residual stand density of 300, 400 and 600 stems ha^{-1}.

These differences in volume are reflected in the gross standing value of the different treatment combinations. The maximum value (\$106,000 ha^{-1}) was produced by the GF25 rated seedlot in the 400 stem/ha un-pruned stand while the lowest value (\$51,000 ha^{-1}) was produced by the GF13 rated seedlot in the 1000 stems ha^{-1} un-pruned stand (Figure 4). This difference was due to a combination of low volume, coupled with small stem diameters and poor stem form. Low standing values were also produced by all seedlots in the 200 stems ha^{-1} pruned stands. Most of the volume produced by the GF25 rated seedlot was in the S1, S2 and S3 grades (Figure 5), whereas the GF13 rated seedlot produced a much higher proportion of pulp and K grade logs. Wider-spaced stands also had a higher proportion of A grade logs.

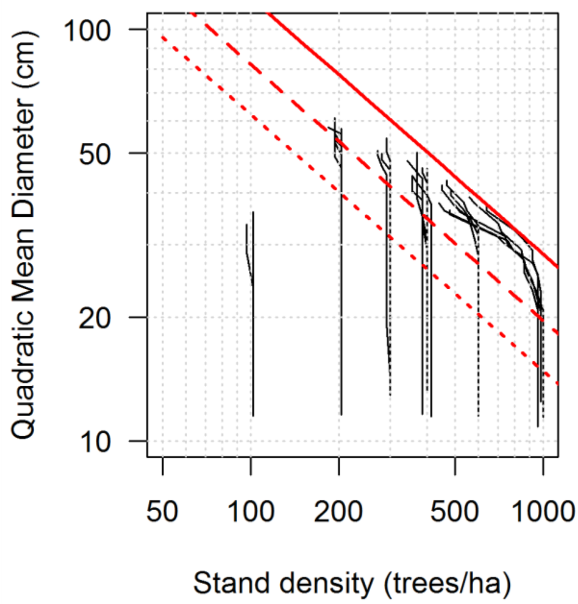

Figure 3: Density management diagram showing the development of each plot in the FR121/2 trial. The maximum size-density line is shown as a solid line, with the dashed and dotted lines corresponding to 55% and 35% of this maximum, respectively.

The average value of breast height outerwood density (BHOWD) across all treatment combinations was 414 kg m^{-3}. On average, BHOWD was 17 kg m^{-3} lower in the GF25 rated seedlots compared with the GF7 rated seedlots. There was not a strong relationship between stand density (stocking) and wood density (Figure 6). On average, wood density was 28 kg m^{-3} higher in the 1000 stems ha^{-1} treatment compared with the 100 stems ha^{-1} treatment. The relationship between stand density and stiffness measured as HM200 acoustic velocity) was more apparent (Figure 6). In the unpruned stand thinned to 200 stems ha^{-1}, HM200 velocity was 2.78 km s^{-1}, increasing to 3.09 km s^{-1} in the unpruned, un-

[1] Indicative log prices provided by MPI accessed at http://www.mpi.govt.nz.

thinned stand planted at 1000 stems ha^{-1}. Seedlot differences were less apparent. The GF25-rated seedlot had a slightly lower HM200 velocity than the GF7-rated seedlot, but the difference was only 0.06 km/s (1.9%) and therefore of little practical significance.

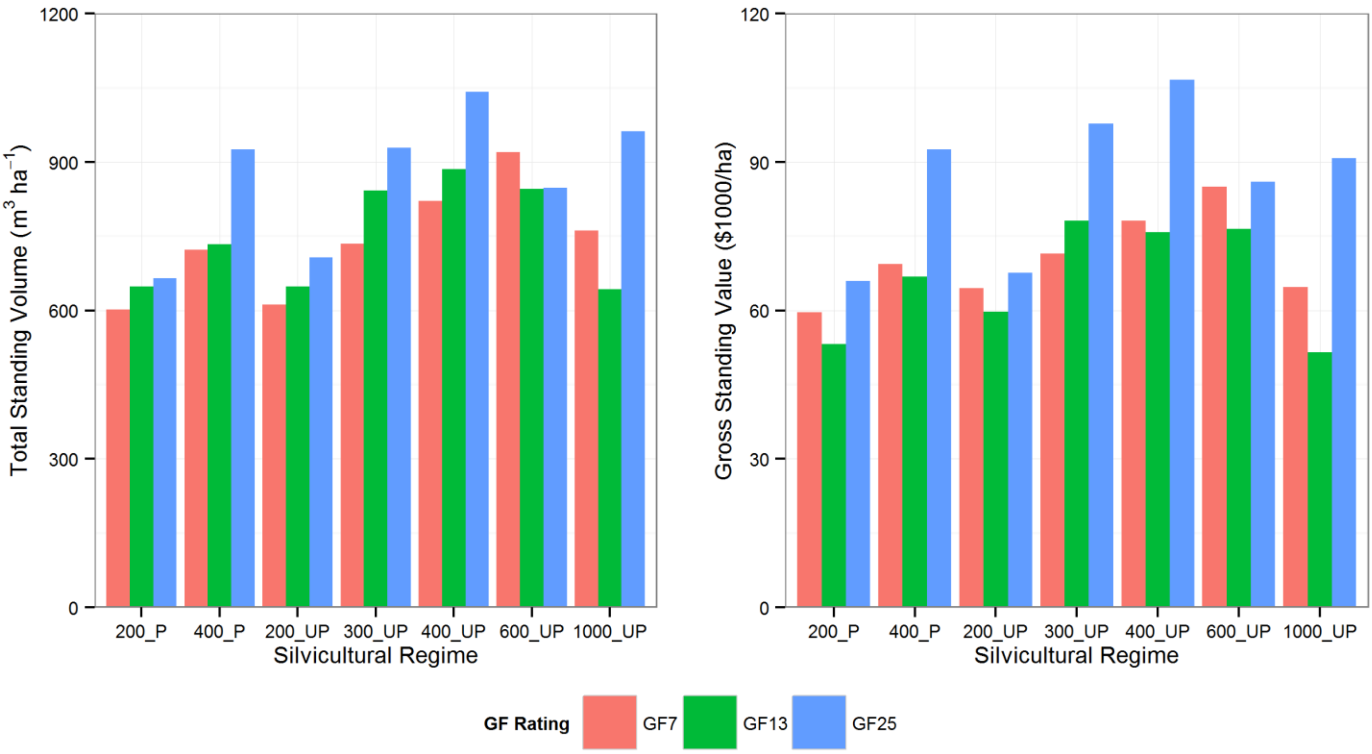

Figure 4: Comparison of total standing volume and gross standing value between treatment combinations. The silvicultural regimes are referred to by their post-thinning stand density and whether they were pruned (P) or not (UP).

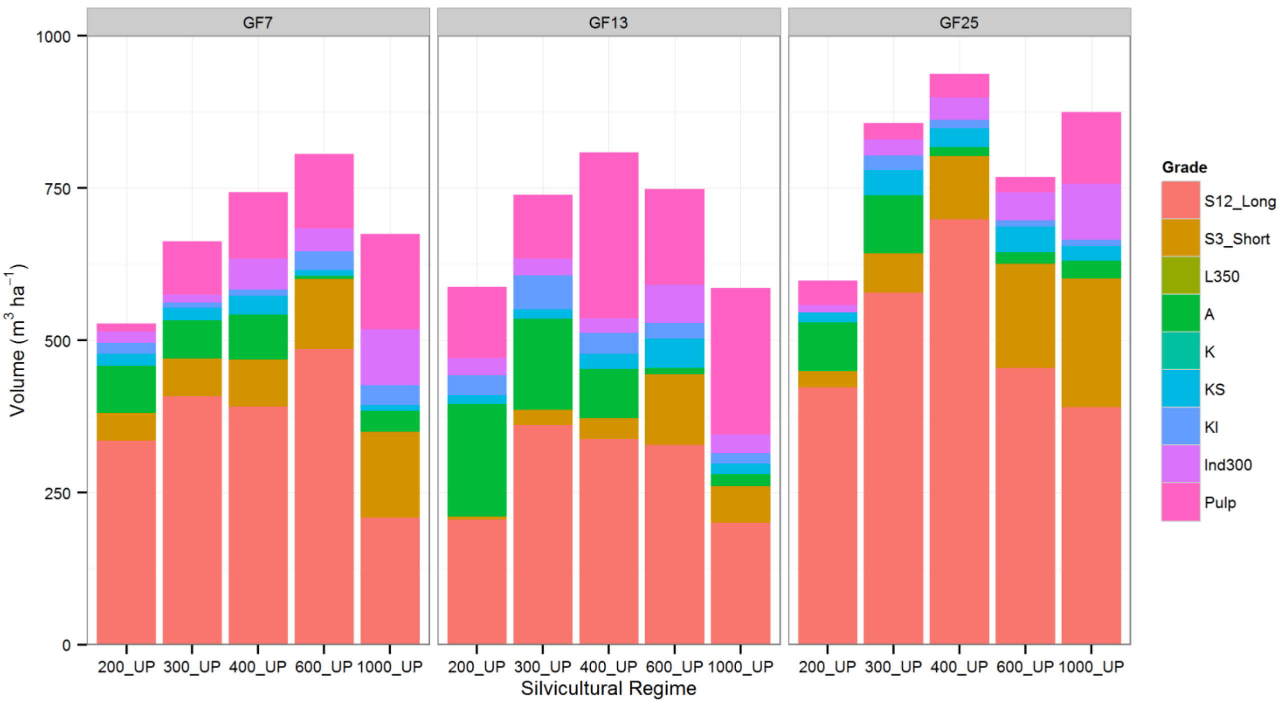

Figure 5: Comparison of log grade outturn between selected treatment combinations. The silvicultural regimes are referred to by their post-thinning stand density. Data are presented for the un-pruned treatments only. See Appendix 1 for more information on the log grades.

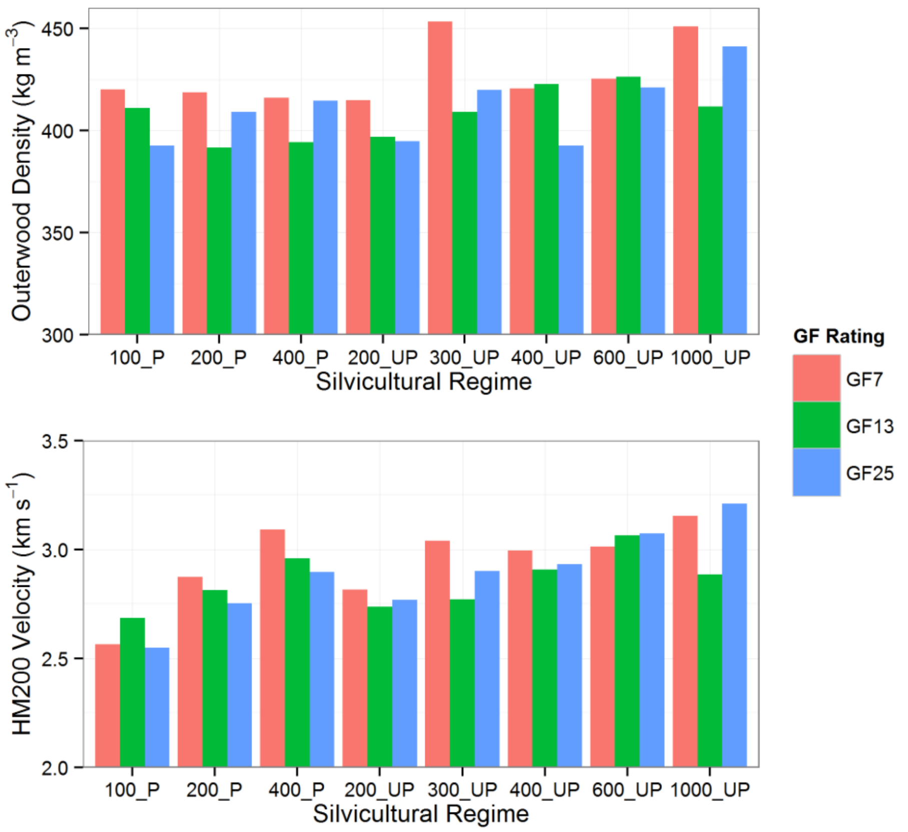

Figure 6: Comparison of wood density and HM200 velocity between selected treatment combinations. The silvicultural regimes are referred to by their post-thinning stand density and whether they were pruned (P) or not (UP).

Discussion

These preliminary results show that stand volume production is maximised at a residual stand density after thinning of 400 stems ha^{-1}. This is consistent with those obtained from earlier mid-rotation assessments of silviculture breeds trials [14, 15] and other experiments [10-12]. The site is not fully occupied at lower stand densities (i.e. 100 and 200 stems ha^{-1}), while at higher stand densities the site is overstocked in the latter stages of the rotation, with the intense competition resulting in a reduction in growth and substantial mortality. In the un-thinned plots, the peak in volume production was reached between 15 and 20 years, which is well below the typical rotation age for radiata pine stands grown in New Zealand. In order to maximise volume production, the aim should be to ensure that the peak in MAI occurs at the target rotation length.

The trends in gross value generally followed the trends in volume. Log price information used in this analysis was obtained from the Ministry for Primary Industries in February 2015. Therefore changes in log prices and the relative log prices between grades will affect the overall gross values, but the broad trends would be expected to be maintained.
It is important to note that pruning was to a height of only approximately 2.7 m. As a result, there were no pruned logs produced, which would have affected the value of these stands. If a significant proportion of the volume in the S1 and S2 grades was moved into the P1 and P2 grades, which have a \$15-40 m^{-3} price premium based on the pricing used, this would increase the standing value of the pruned stands. However, even if 50% of the S1 and S2 logs were allocated to the P1 and P2 grades, the gross standing value of the 400 stems ha^{-1} pruned stand would still be less than the value of the unpruned stand thinned to the same density.

The effect of stand density was consistent with results from other trials, including the mid rotation assessment of trials in this same series [14, 15]. Our results showed that there was a general increase in breast height outerwood density with increasing stand density. The relationship between stand density and estimated stiffness (HM200 velocity) was more apparent. Many of the earlier studies that have investigated these relationships have done so in comparatively young stands, i.e. aged between 11 and 17 years of age [10, 11, 14, 15]. Fewer data are available from older stands in which the differences between treatments would be expected to be greater due to the relative impacts of competition.
The GF25 rated seedlot had a relatively low GF Plus rating for wood density (10.2) based on the 2012 breeding values. Its corresponding GF Plus rating for growth was 20. Therefore its lower breast height outerwood density was not unexpected, although we do not have a wood density rating for the GF7 seedlot for comparison. Data from this trial, along with those from other trials, are being used to

validate the genetic adjustments to the wood density model that is implemented within Forecaster [18].

In addition to using these trials for quantifying realised genetic gain in wood density, the volume and grade outturn at the end of rotation will also be used to assess the impacts of genetic improvements in growth and stem form. Data from large plot trials such as this are extremely rare, and the end of rotation assessment of these trials represents a unique opportunity to quantify the impacts of past genetic selections.

Further work will focus on better understanding the intra-stem patterns in wood properties through analysing the pith-to-bark cores and discs that were collected. This will provide more insight into the impacts of silviculture and seedlot on end-product quality. Other installations in the trial series will also be assessed as they reach maturity, which will provide more evidence of the impacts of silviculture and seedlot on growth and wood properties across a broad range of sites.

Acknowledgements

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Appendix 1

Table A1: The log grade specification and pricing used in the yield analysis. Log specifications and process adapted from Agrifax regional log pricing report February 2015

Grade	Price ($/m^3)	SED (cm)	LED (cm)	Lengths (m)	Max. knot (cm)	Max Sweep*
P1	162	40	85	3.7, 4.8	0	4
P2	135	30	85	3.7, 4.8	0	4
S12_Long	120	30	90	4.9, 5.5, 6.1	7	4
S3_Short	107	20	90	3.7, 4.8	7	4
L350	102	35	80	4.9, 5.5, 6.1	12	4
Ind300	91	10	99	3-6@0.5	25	3
Pulp	52	10	NA	3.7-6.2@0.5	NA	1
ExportP	171	36	NA	4	0	4
A	114	30	NA	3.7, 5.5, 6.1	10	4
K	105	22	34	3.7, 5.5, 6.1	15	4
KS	106	20	26	3, 6.4	15	4
KI	99	26	NA	4	25	3

* Sweep defined as the allowable deviation from a straight line as a proportion of the SED over the log length