WOOD PROPERTIES OF TWENTY HIGHLY RANKED RADIATA PINE SEED PRODUCTION PARENTS SELECTED FOR GROWTH AND FORM

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ABSTRACT

Twenty highly ranked radiata pine (*Pinus radiata* D. Don) seed production parent trees, grown under a commercial sawlog regime, were destructively assessed at rotation age (27 years) for wood quality traits significant to solid-wood and veneer products, including: juvenile-wood density, density variation, juvenile-wood spiral grain, compression wood, and appearance characteristics such as within-ring internal checking and resin pockets. Traits varied considerably among parents, which is reasonable since breeding efforts in New Zealand have, until recently, focused primarily on stem productivity and form. Parental information is useful for many wood properties owing to their high heritabilities in radiata pine (usually 50–80%); thus production forests established using advanced-generation genetic materials can also be expected to be variable in wood properties. Like other fast-grown pines, much of the radiata pine crop is juvenile wood, and an important challenge for tree improvement is to ensure that juvenile wood properties meet processor and end-user requirements.

Keywords: Genetics, heritability, juvenile wood, *Pinus radiata*, selection criteria, wood quality.

INTRODUCTION

Like most forest tree improvement programs, the New Zealand breeding program for radiata pine has traditionally focused principally on improving growth rate and stem form (Carson 1987; Vincent 1987a). Two special-purpose breeds have also been developed, one with longer internodes and another with improved resistance to Dothistroma needle-blight. There have been large realized genetic gains in stem straightness and stem diameter growth that have enabled reductions in rotation length; but this has increased the proportion of juvenile wood (first 10 annual rings, Cown 1992b) in the harvest and there has been little progress made in breeding directly for wood quality characteristics.

This situation presents, at once, a challenge for the processors and marketers of New Zealand radiata pine and an opportunity for tree breeders. The challenge comes from the variability in wood quality and the difficulty processors have in optimizing processing conditions and achieving reliable product performance when the wood resource has highly variable material properties. In the short term, these challenges are addressed through resource segregation and new systems for monitoring and tracking resource characteristics. In the medium term, there are opportunities for

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new process and product development, and in the longer term, our breeders hope to capture significant value gains through selection and breeding for improved wood quality by utilizing the existing variability in wood properties among parents in the breeding population. Another possibility is the modification of wood and fiber quality through genetic engineering.

The need to define wood quality in terms of an intended end use is well established and has been emphasised by many authors (e.g., Zobel and van Buijtenen 1989, p. 2; Crown 1992a; Jozsa and Middleton 1994). Most view New Zealand-grown radiata pine in terms of its fitness for conversion and use as solid wood products. From the 1960s there has been widespread use of pruning with the aim of manufacturing long-length clearwood products such as moldings, joinery, furniture components, and veneers. New Zealand's pruned log harvests are forecast to increase fourfold (to 4.5 $\times$ 10^3 m^3 inside bark) over the next decade (New Zealand Ministry of Forestry 1996). Unpruned logs are used for structural wood or knotty veneer unless the clear lengths are long enough to produce shop and factory grades of lumber. Lower quality wood is used for packaging, and residues are used for pulp and papermaking and for other reconstituted products.

Wood quality traits, if they have been considered by tree breeders at all, have generally been afforded only secondary importance in the past (Zobel and Jett 1995, p. 2). This is not to say that tree breeders and wood technologists have not been aware of the opportunity to improve wood quality traits, but rather that forest growers have generally valued growth performance and stem form more highly. In New Zealand and in other countries with advanced tree improvement programs, there is now a growing appreciation by forest owners of the value creation opportunities associated with breeding for improved wood quality. At least in part, this has occurred because of a shift in forest assessment criteria away from log grades based primarily on external log characteristics (small-end diameter, sweep, maximum branch size, etc.) to criteria that attempt to more accurately capture end-product value.

Burdon (1995) has also suggested that for New Zealand radiata pine, continued high emphasis on selection for tree form might not be warranted given the improvement already achieved. He further argued that there was finite scope for gains in productivity given the constraints imposed by the environment and considering fundamental aspects of shoot architecture and physiology. All of these types of arguments lead breeders to increase their focus on wood properties.

The objective of this paper is to demonstrate the variability in wood quality existing among highly ranked New Zealand radiata pine seed production parents. Although the study is exploratory, it is noteworthy in that it concerns wood properties of second-generation selections at rotation age. The wood properties assessed (juvenile-wood density and spiral grain, density variation, compression wood, and appearance characteristics) are considered to have a very significant bearing on end-product value in radiata pine.

MATERIALS AND METHODS

Plant material

In 1968, plus-trees were selected from landrace materials in the northern parts of Kaingaroa Forest in the Central North Island of New Zealand. This forest was largely established from seed collected from Central North Island forests early this century. The plus-trees were selected at a rate of about one tree per 1.2 ha from 12- to 18-year-old stands, using diameter at breast height (1.4 m), stem straightness, light branching and freedom from stem malformation as selection criteria, and diameter given the strongest weighting. Cones were collected, and in 1969 progeny trials were established at three North Island sites, including Kaingaroa, that contained the open-pollinated progenies of 588 plus-trees. The Kaingaroa trial had five block replicates with one 10-tree row-plot per family per block. Trees were planted at a spacing of 2.7 $\times$ 2.7

m (approximately 1330 stems per hectare) and later access pruned to about 3 m.

At age five, diameter at breast height (dbh), bole straightness, and branch quality were assessed; and for the better families, tree height and wood density in rings 2–4 were also measured. The best individuals in the top families were collected as scions and placed in seed orchards. Then, at age ten, dbh, bole straightness, branch quality, forking, density (Pilodyn penetration), and susceptibility to *Cyclaneusma* needle cast were assessed; and a combined multi-trait, within- and between-family index was used to reselect top families. The best individuals from this second round of forward selection were cloned and used in seed orchards for controlled-pollinated seed production and in the development of advanced radiata pine breeds within New Zealand.

At 18 years, the progeny trial was thinned to 300 stems per ha, and in 1996 twenty of the highly ranked 27-year-old second-generation selections were destructively sampled to assess log characteristics, wood properties, and lumber quality. Of the 20 parents sampled, two are heavily used for industrial seed production and seven are used regularly.

Discs were collected from the butt, breast height, and all 5-m log lengths to a stem diameter of about 10 cm. All trees had discs collected at 30 m (top of log 6), and a few had discs collected from 35 and 40 m. For the purposes of this study, parents were compared on the basis of the first six logs only, and results are presented separately for the butt logs. A short pruned log was also collected between the butt and breast height to assess sawn lumber properties.

Wood property assessment

Wood properties, including compression wood, juvenile-wood density, density variation, and juvenile-wood spiral grain were assessed on the discs, and then average values were estimated for each log. The assessment of compression wood sought to identify the mild, "all-around" compression wood that can occur around the full circumference of fast-grown stems. The intention was to differentiate this from the compression wood associated with the underside of leaning stems. To do this, each disc was divided into quadrants; and the occurrence of compression wood in each quadrant was scored 0, 5, 10, 15%, etc., on the basis of area affected. Discs were deemed to contain mild, all-around compression wood if three or more quadrants were at least 10% affected. A score of 0 to 3 was then applied to each butt log depending on the number of discs (butt, 1.4, and 5 m) with all-around compression wood. For the upper logs (2–6), a score of 0 to 3 was also applied depending on the occurrence of all-around compression wood in discs at 5, 10, 15, 20, 25, and 30 m; e.g., two affected discs scored 1 and five affected discs scored 2.5. A very weak association was found between this index of mild, all-around compression wood and tree lean (Spearman Rank correlation coefficient, r_s = 0.10 for the butt logs and r_s = 0.18 for the upper logs. Note, however, that these statistics should be interpreted with caution because of the large number of tied observations).

For wood density analysis, sectors were sawn from each disc and then divided into 5-ring groups; rings 1–5, 6–10, etc., with the outer ring group containing between 3 and 7 rings. For each segment, the green volume was determined by water displacement, the oven-dry weight was recorded, and the basic density was computed (kg m^{-3}). Density of rings 1–5 and 6–10 was used to calculate the volume-weighted juvenile-wood (rings 1–10, Cown 1992b) density for each log. For the three discs associated with the butt log, the difference between the highest and lowest density 5-ring groups (juvenile wood and mature wood) was defined as the density variation. This was intended to be an estimate of the variation in board density that could be expected from the butt log. The 5-ring segments were roughly comparable in cross-sectional dimensions to the ends of small boards. A similar process was also used for the upper logs.

Spiral grain was measured in each disc in two directions from the pith, 180 degrees apart and oriented in a way that avoided knots or other localized grain deviations. Rings 2, 4, 6, 8, and 10 were assessed by exposing the latewood with a chisel, scribing the grain, and measuring the grain angle in relation to the lower surface of the disc using a perspex protractor (Harris 1989). Values for each disc were averaged to obtain the juvenile-wood spiral grain, and disc values were averaged to estimate values for butt logs and upper logs.

Sawn lumber assessment

Two 50-mm-thick boards and a 100-mm cant were sawn from each short pruned log recovered between breast height and the butt. The 1.4 m-long boards, containing a mixture of sapwood and heartwood, were kiln-dried using an accelerated drying schedule for radiata pine (90/60°C dry/wet bulb temperatures) to a target moisture content of 12%, and the severity of kiln brown stain development was described as light, moderate, or severe using visual assessment of color and stain distribution (Kreber et al. 1996). Final steam conditioning was not performed at the completion of drying because this is known to accentuate the development of kiln brown stain. Boards were then surfaced on both faces, assessed for resin pockets, blemishes (resin streaks, bark pockets, and other colored marks), needle traces, and compression wood, then cross-cut and assessed for within-ring internal checks, which are sometimes observed in rapidly grown stems (Booker 1997; Miller and Simpson 1992).

RESULTS

Wood properties

All of the measured wood properties showed high levels of variability between parents (Table 1). In the butt logs, juvenile-wood density (defined by the inner 10 rings) ranged from 338 to 413 kg m^{-3}, and juvenile-wood spiral grain ranged from 1.8 to 6.0 degrees. All-around compression wood scores ranged from 0 (not detected) to a maximum value of 3 (detected in all three discs of the butt log). Density variation ranged from 101 to 201 kg m^{-3}. Considerable variability between parents was also evident in the upper logs (Table 1). Individual parents had various combinations of desirable and undesirable characteristics; e.g., parent number 16 had relatively high juvenile-wood density, low juvenile-wood spiral grain angle, and an all-around compression wood score of 0, meaning that it would be a highly desirable parent insofar as wood quality. In contrast, parent 19 had relatively high juvenile-wood density but one of the highest juvenile-wood spiral grain angles, and parent 3 had all-around compression wood throughout the butt log and very low juvenile-wood density.

Correlations between butt-log and upper-log properties ranged from 0.69 for spirality and juvenile-wood density to 0.81 for compression wood score (Table 2), meaning that information from butt logs is generally useful for predicting properties of upper logs. Correlations between butt-log properties were very weak and not statistically significant ($\alpha = 0.05$), except that there was a modest tendency for parents with higher density juvenile wood to also have larger radial density variations ($r = 0.47$, df = 18, $P < 0.05$; Table 3). Because of the generally high heritabilities for wood properties, we consider these correlations to be meaningful estimates of the genetic correlations between these traits.

For these 20 parents, the correlation between dbhob (diameter at breast height over bark) and breeding value for dbhob (BVdiam) was a mere 0.25, which is not surprising considering the low heritability for this trait. To estimate genetic correlations between diameter growth and wood properties the BVdiam for each parent was therefore used (Table 3). These correlations proved to be very weak and nonsignificant except for the correlation between BVdiam and juvenile-wood spiral grain ($r = 0.36$; Table 3). In comparison, another recent estimate of this genetic correlation based on a larger sample of 184 parents provided an estimate of $r = 0.02$ (Sorensson and

TABLE 1. *Butt-log and upper-log (2–6) wood properties for the twenty highly-ranked 27-year-old radiata pine seed production parents.*

	Butt log				Logs 2–6			
Parent	All-around compression wood score	Juvenile wood density (kg m^{-3})	Density variation (kg m^{-3})	Juvenile wood spiral grain (deg)	All-around compression wood score	Juvenile wood density (kg m^{-3})	Density variation (kg m^{-3})	Juvenile wood spira grain (deg)
1	0	363	101	3.3	0	371	122	2.9
2	0	362	133	4.5	0	367	102	7.3
3	3	365	141	3.1	0.5	363	116	3.1
4	2	338	101	3.7	0.5	348	98	4.8
5	0	365	162	4.8	0	352	155	6.5
6	0	387	137	1.8	0	380	119	4.0
7	0	352	124	2.6	0	349	124	2.1
8	0	388	136	5.8	0	362	144	6.0
9	0	356	148	5.4	0	358	108	6.6
10	0	407	170	4.7	0	387	137	6.2
11	0	367	114	3.1	0	360	141	5.1
12	3	364	144	2.6	0.5	348	124	4.0
13	0	404	201	2.8	0	378	206	5.2
14	1	384	125	3.1	0	398	125	6.2
15	0	358	147	2.8	0	371	130	4.6
16	0	413	166	2.3	0	370	129	4.4
17	0	384	182	3.5	0	365	175	4.1
18	3	395	116	3.0	1	368	115	4.7
19	0	401	163	6.0	0.5	387	151	6.1
20	0	410	120	2.6	0.5	380	149	3.4
Min	0	338	101	1.8	0	348	98	2.1
Max	3	413	201	6.0	1	398	206	7.3
Mean	0.6	378	142	3.6	0.2	368	133	4.9
CV (%)		5.8	18.7	33.9		3.8	19.1	28.7

Gea unpublished data). Interestingly, there was no apparent correlation between BVdiam and compression wood score.

Lumber quality

All of the boards developed severe kiln brown stain (Table 4), and most parents had at least trace levels of all-around compression wood. Three of the parents had boards with moderate compression wood, two had resin pockets, and two had within-ring internal checking. Nine of the 20 parents had one or more blemishes on the butt log boards. Blemishes included resin streaks, bark inclusions, and other colored grain deviations that were not associated with knots.

TABLE 2. *Correlations between butt-log and upper-log properties. Product Moment correlation coefficients are shown except for compression wood score, where the Spearman Rank correlation coefficient is used. All are significant at 0.01 level.*

Property	Correlation coefficient
Compression wood score	0.81
Juvenile-wood density	0.69
Density variation	0.70
Juvenile-wood spiral grain	0.69

DISCUSSION

Genetically improved radiata pine seedlots are marketed in New Zealand using breed codes and improvement ratings (Vincent 1987b). The GF (growth and form) breeds are improved in growth and form with the major characteristics being increased volume, stem straightness, a short-internode branching habit, and less malformation. The majority of radiata pine used by the New Zealand forest industry is included in this breed. The GF improvement

TABLE 3. *Correlations between butt-log properties and breeding values for dbhob (BVdiam). Product Moment correlation coefficients are shown except for tests with compression wood score, where the Spearman Rank correlation coefficient is used. Bold entries are significant at 0.05 level.*

	Compression wood score	Juvenile-wood density	Density variation	Juvenile-wood spiral grain
Compression wood score				
Juvenile-wood density	0.08			
Density variation	−0.03	**0.47**		
Juvenile-wood spiral grain	0.10	−0.04	0.17	
BV diam	−0.09	−0.16	−0.27	0.36

ratings are calculated using estimates of the genetic worth of the parents and the contribution of each parent tree to the seedlot. Roughly two-thirds of the rating is for diameter growth, and the remaining third is for stem form. Unimproved seed has GF ratings of 1–3, and forms the benchmark for volume comparisons and the percentage of acceptable stems. Typical controlled-pollinated seedlots are rated GF 22–25 and have an expected volume gain of 27–32% and an increase in the percentage of acceptably formed stems from 45 to 80% (Vincent 1987a). A controlled-pollinated seedlot with equal contribution by each of the 20 highly ranked parents studied in this project would have a GF rating of 23. A kg of GF 23 seed is currently priced at around N$3,500. Considered as a group, the 20 parents tested have a mean diameter at breast height that is 1.14 standard deviation units above the mean for the entire New Zealand radiata pine breeding population (at 27 years of age, the average height and diameter at breast height were 41.6 m and 54.7 cm; the log volume ranged from 1.92 to 5.15 m^3).

The 20 highly ranked parents can be considered highly variable in wood quality at rotation age based on the coefficients of variation in Table 1. Resin pockets and within-ring internal checks were also associated with only some of the parents (Table 4). An exception

TABLE 4. *Wood quality characteristics of boards sawn from the butt log of twenty highly ranked 27-year-old radiata pine seed production parents. +, − refer to presence, absence.*

Parent	Kiln brown stain	Resin pockets	Blemishes (no.)	Needle traces	Compression wood	Internal checks
1	severe	−	2	−	trace	−
2	severe	+	−	−	trace	−
3	severe	−	3	−	mod	−
4	severe	−	−	−	trace	−
5	severe	−	−	−	trace	−
6	severe	−	3	−	trace	−
7	severe	+	−	−	trace	−
8	severe	−	−	−	trace	−
9	severe	−	−	−	−	+
10	severe	−	1	−	−	−
11	severe	−	2	−	trace	+
12	severe	−	−	−	mod	−
13	severe	−	−	−	trace	−
14	severe	−	1	−	trace	−
15	severe	−	2	−	trace	−
16	severe	−	2	−	trace	−
17	severe	−	−	−	−	−
18	severe	−	−	−	trace	−
19	severe	−	−	−	mod	−
20	severe	−	1	−	trace	−

was kiln brown stain, which was severe for all parents. Juvenile-wood density was seemingly less variable than other wood properties (CV < 10%), although for this important characteristic, this degree of biological variation is considered quite large enough to offer scope for economic gain. These results are not surprising, considering the history of selection that has mainly been for growth and form characteristics. Although this study did not allow a quantitative comparison to be made with unimproved radiata pine, it is reasonable to assume that most of the original variability in wood quality characteristics is still retained by the New Zealand radiata pine breeding population.

Narrow-sense heritability estimates for many radiata pine wood properties are in the range of 50–80% (Table 5). Assessments of parental phenotypes can therefore be useful for predicting progeny characteristics, and we consider the intensively assessed rotation-age wood properties of these second-generation selections to be indicative of the wood prop-

TABLE 5. *Narrow-sense heritability estimates at the level of the individual (h^2) and phenotypic coefficients of variation (CVp) for radiata pine wood quality traits. Note that these studies vary in number of families, progeny per family and sites assessed.*

Wood property	h^2	CVp (%)	Rings or (Age)	Reference
Heartwood %	0.49	39	(20)	Cown et al. (1992)
Resin content	0.51	37	1–5	Cown et al. (1992)
Resin content	0.45	65	6–10	Cown et al. (1992)
Resin content	0.37	69	14–18	Cown et al. (1992)
Spiral grain	0.73	60–80	7–8	Sorensson and Lausberg (1996)
Spiral grain	0.65	40–46	2 & 5	Burdon and Low (1992)
Spiral grain	>0.8	45		Burdon (1992)
Compression wood	0.64	68	1–18	Cown et al. (1992)
Microfibril angle	<0.6	8	1–15	Donaldson and Burdon (1995)
Basic density	0.92	7	1–5	Cown et al. (1992)
Basic density	1.0	8	6–10	Cown et al. (1992)
Basic density	1.0	9	14–18	Cown et al. (1992)
Basic density	0.5–0.9	6	1–5	Burdon and Low (1992)
Basic density	0.6	7	1–5	Bannister and Vine (1981)
Basic density	0.68	7	6–10	Bannister and Vine (1981)
Basic density	0.51	8	11–15	Bannister and Vine (1981)
Radial density gradient	0.27	45	1–15	Bannister and Vine (1981)

erties that will occur in forests originating from advanced-generation seedlots. The 20 highly ranked parents have not been subjected to selection for wood properties, except to a minor extent with wood density; and although the sample is small, there is no reason to suspect that these parents are not broadly representative of seed orchard clones used to produce controlled-pollinated, high GF-rated seed in New Zealand.

The implication for New Zealand forestry, and other countries/organizations with similarly designed genetic improvement programs, is that wood in production forests can also be expected to be highly variable in terms of basic properties. The actual clones used to produce high GF-rated seed vary among forestry companies and seed producers. However, without *a priori* knowledge of most wood properties for the selections, it is inevitable that most seedlots contain a variable mixture of wood quality genotypes. Investment in technologies for evaluating the wood quality of logs and lumber will be needed to utilize this resource wisely.

For this project, our focus was on juvenile wood properties, wood uniformity, and butt-log appearance characteristics because these are considered to be important for utilization of short-rotation radiata pine for solid-wood products. An industry vision for New Zealand radiata pine in the year 2020 is for harvesting at age 15 to 20 years (FAFPRO 1997). Thus, at least half of the future resource will be juvenile wood, which has inferior wood properties for most solid-wood uses. The tree improvement challenge is to grow juvenile wood with properties that meet end users' requirements. Minimum wood qualities for radiata pine have been suggested to be 400 kg m^{-3} for density (Cown 1992b) and spiral-grain angles less than 5 degrees (Cown et al. 1991, 1996).

It would be desirable if genotypes with improved juvenile wood properties were also likely to have reduced within-tree wood property variation, a breeding objective advocated by Zobel et al. (1983). However, the moderately positive correlation between density variation and juvenile-wood density (Table 3) suggests that with respect to density, the opposite may be more common. Donaldson et al. (1995) reported an analogous situation for clones of radiata pine where a strong correlation (r = 0.89) was found between earlywood and latewood densities. They considered there to be limited opportunities for genetic improvement of within-ring density uniformity.

Also important in New Zealand are wood-quality characteristics that affect clearwood recovery from pruned logs. A simplistic view of the recovery of long-length clears considers only log diameter and the size of the knotty core; however, internal wood-quality characteristics such as resin pockets, resin streaks, blemishes, and internal checks are also significant. Compression wood was assessed because of its undesirable color and because it can lead to excessive longitudinal shrinkage, which is a major cause of distortion and dimensional instability.

Compared to heritability estimates for stem volume, stem diameter, tree height, or stem straightness (typically <0.2; Shelbourne and Low 1980; Burdon 1991, 1992; Burdon et al. 1992), the heritability estimates for many wood properties are high (Table 5), meaning that improvement by selection and breeding will be feasible. The relationships between wood properties and end-product value are difficult to define quantitatively because of the large number of interrelated wood property variables and the variety of processing technologies and product options. Implications for selection could also depend very much on choice of planting site, tending regime, and intended rotation age. Nevertheless, there is widespread acceptance that the economic impacts of density, spiral grain, and uniformity provide sufficient justification for improvement. The tree-to-tree variation in these 20 highly ranked second-generation selections also indicates the potential to achieve directed changes in wood quality through clonal selection and deployment. It may even be possible to identify clones that are suited to particular product types or manufacturing systems. That said, what is also evident is that some of the highly ranked parents selected on the basis of growth and form characteristics had poor wood quality according to present end-use requirements. The progeny of some of these highly productive clones with undesirable juvenile wood properties will on average have low value for mass deployment using clonal forestry unless complementarily mated. A future priority will be the development of techniques for rapid and cost-effective screening of wood quality in clonal trials.

Considering wood quality characteristics that affect clearwood recovery in pruned logs (resin pockets, internal checking, etc.), it is important to note that phenotypic variation is still poorly characterized and the degree of genetic control is largely undefined. Thus, it is difficult to assess the potential for genetic improvement. A conservative approach might be to assume at least moderate broad-sense heritability, which would lead to large-scale deployment of only those materials that are not severely affected. A significant barrier to this would be the costs of assessment and the age at which screening is likely to yield reliable information. There may also be technical, wood processing solutions to within-ring internal checking and kiln brown stain formation which provide more immediate results.

CONCLUSIONS

By destructively assessing rotation-age trees for wood properties, we have demonstrated the variability in wood quality existing among twenty highly ranked New Zealand radiata pine seed production parents. All of the measured wood properties showed high levels of variability between parents, reflecting the history of selection, which has predominantly been for stem productivity and form; and the finding that correlations between wood properties and breeding values for stem diameter are generally very weak and nonsignificant. Clearly, this has been an exploratory study; however, similar detailed assessment of progeny would probably be prohibitively expensive assuming a minimum requirement for replication of fifteen trees per family. Assessments of parental phenotypes can be useful for predicting wood quality characteristics of progeny because of the high narrow-sense heritabilities for many radiata pine wood properties (usually 50–80%).

We consider the variability in wood properties observed in these rotation-age, second-generation selections to be indicative of the variability that will occur in forests originating from advanced-generation seedlots. As such, the study also provides some directions for future research. In particular, there is the need to improve processing systems to convert a juvenile wood resource with variable material properties into products with consistent and reliable qualities. To a large extent this will depend on having techniques and equipment for segregation and resource allocation on the basis of wood quality characteristics. Wood properties and end-product traits are expensive to assess relative to dbh, stem form, and height. However, high heritabilities support the forwards selection approach, and we are planning to extend our investigation of the parent-offspring relationships for wood quality traits such as propensity to form resin pockets and within-ring internal checks.

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