Minimising growth-strain in eucalypts to transform processing

Ministry for Primary Industries Sustainable Farming Fund Project 407602

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Contents

Executive Summary: Minimising growth strain in eucalypts to transform processing

- A four-year MPI Sustainable Farming Fund project 407602 was undertaken at the University of Canterbury School of Forestry (2015-2019).
- The driver for the project was the perceived opportunity for high-stiffness eucalypt veneers to be manufactured by New Zealand laminated veneer lumber (LVL) processors. High-value international markets exists for LVL. Eucalypts are well-suited to this end use, because of their high stiffness and homogenous density.
- Two current constraints which deter manufacturers from using eucalypts in LVL are: (i) growth strain in eucalypts, which causes logs to split when harvested and sawn, and (ii) there is no large-scale, quality eucalypt resource near the processing plants.
- Both these constraints have the potential to be overcome by the on-going NZ Dryland Forests Initiative breeding programme, which aims to breed genetically improved durable eucalypts as the basis for sustainable home-grown durable hardwood industries in New Zealand's dryland regions.
- By identifying the best 'low growth strain' genetic material early in the rotation of selected eucalypt species, it should be possible to speed up its incorporation into the NZDFI breeding programme.
- A series of trials was established, comprising five of NZDFI's highly durable species of known families. The species planted were *E. bosistoana* and *E. quadrangulata*, *E. argophloia, E. tricarpa*, and *E. sideroxylon*.
- The stems of the trees were harvested at age 2 years, with the cut stumps being left *in situ* following harvest and allowed to coppice. The potential to take cuttings from coppice regrowth therefore remained.
- Harvested stems were tested for growth strain using a newly developed rapid assessment technique, which enabled very large numbers of stems to be assessed.
- The sampled trees were assessed for a range of wood properties – growth strain, diameter, density, acoustic velocity, volumetric shrinkage and modulus of elasticity. The heritabilities of, and correlations between, these traits were calculated.
- The assessments enabled the selection of the most promising families in terms of low growth strain and other properties. Cuttings were then harvested from the coppicing stumps of the top-performing families.
- The project successfully supported the development of new clonal propagation techniques for the selected eucalypt species by Proseed in Amberley. *E. bosistoana* clones from top-performing families are now established as stool material for commercial clonal propagation.
- Cuttings taken from the SFF 407602 trials have been successfully propagated. *E. bosistoana* produced from propagation have been planted out in two further low growth strain breeding trials, a highly successful outcome.
- In addition, peeling trials using 30-year-old *E. globoidea* were undertaken in collaboration with Nelson Pine Industries Ltd. The trials demonstrated that veneers of suitable quality could be obtained from the trees, and also demonstrated the importance of low growth strain to maximise veneer yields.
- Various outreach activities have been undertaken as part of the project including three international workshops. The project has also been the subject of numerous student theses and academic publications.

1. Introduction

NZ forestry exports are dominated by unprocessed products. Opportunities to raise export earnings by increased processing of locally grown timber and exporting value-added products have long been recognised, but little has been achieved.

While development of new large-scale wood processing facilities would be desirable, this requires substantial investment and long-term planning. As an alternative, a gradual increase in production from existing domestic processing facilities could be introduced with much lower costs and barriers, and with more certain outcomes.

LVL (laminated veneer lumber) is one high-value product (\$800-1400/m^3) which can contribute to increased export earnings, and for which domestic and international markets exist. LVL is a structural product and its price is closely linked to its mechanical performance (e.g. stiffness). Only the stiffest (best quality) radiata pine logs can be used in LVL production. However, LVL manufacturers struggle to source enough high stiffness logs and even those produce only an average grade commodity LVL product (11-12GPa valued at \$800/m^3).

"*The best NZ pine is not sufficiently stiff (only 11-12 GPa) to compete on world markets for long-span engineered wood products that require 16 GPa*" (Sheldon Drummond, CEO Juken; Murray Sturgeon, CEO Nelson Pine Industries).

This is where the opportunity for eucalypts arises. Eucalypts have homogeneous density (i.e. yield excellent veneers), can glue well and are super stiff (>20 GPa). The veneer obtainable can be manufactured into high-value LVL (\$1400/m^3).

However, two key constraints have to date limited the use of eucalypts in New Zealand LVL production:

- eucalypt logs often split before/during peeling due to large growth-strain
- there is no sizeable, homogenous (single species) resource in the regions where New Zealand's LVL plants are located.

1.1 The opportunity: increased production of high value LVL

Two recent developments in New Zealand were relevant to the project, and we believe will lead to an increase in the use of durable eucalypts for engineered wood products such as LVL:

i. High stiffness eucalypt resource

The NZ Dryland Forests Initiative (NZDFI) is engaged in a large scale breeding programme for high quality highly-durable eucalypts (www.nzdfi.org.nz). While not initially intended for LVL, two of the species selected by the NZDFI (*E. bosistoana* and *E. globoidea*) yield excellent veneer for LVL. Further, LVL would provide a welcome early market (age 10-12), thereby increasing the attractiveness of these species to the farm foresters as well as the larger corporate growers.

ii. Low growth-strain eucalypt resource

New technology (the 'splitting-test' - developed as part of the MBIE *Compromised Wood* programme 2007-12) enables the mass screening of young trees for growth-strain (Chauhan, 2009). For the first time, this allows selection for low growth-strain in a breeding programme. As growth-strain is heritable (Apiolaza 2009, Hamilton and Potts 2008, Murphy et al. 2005) improved planting stock can be obtained which will not split during veneer processing. Low growth-strain trees, although not entirely necessary for the production of naturally durable poles (the original market that NZDFI envisaged for its eucalypts), will open the way for later (age 18-24) production of highest quality sawn timber (comparable to kwila, rosewood, teak), for which the export market possibilities are endless. The Solid Wood Initiative (SWI) identified growth-strain as the principal constraint with high-value eucalypts (Poole at al. 2013).

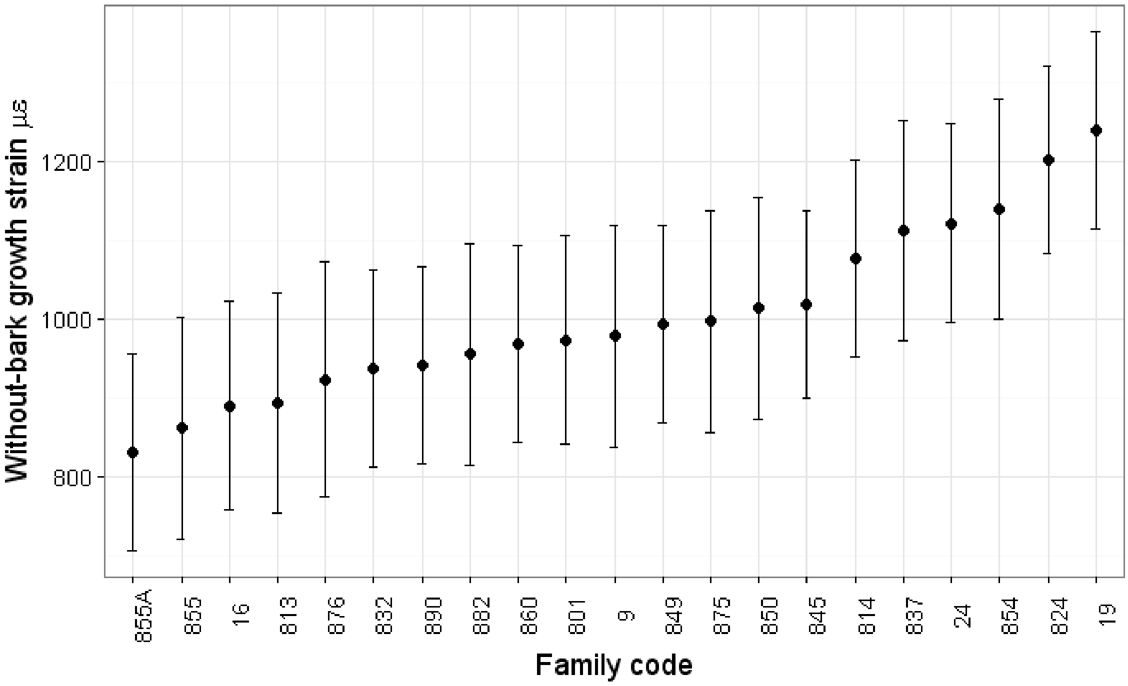


Figure 1: Growth-strain in 1 year-old E. bosistoana families, showing between-family variation which can be exploited depending on its heritability.

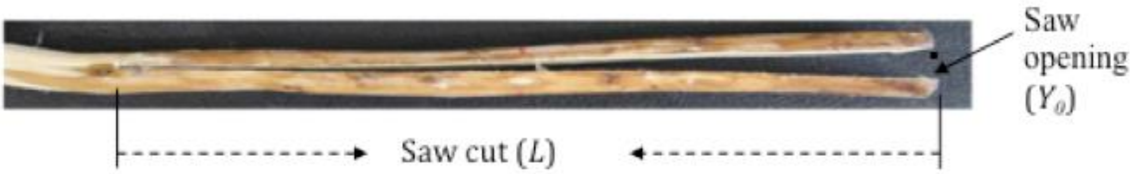


Figure 2: The 'splitting' test: the bigger the opening the greater the growth-strain.

The choice of species

Proseed Ltd is New Zealand's biggest producer of seed for the forest industry. On behalf of NZDFI, Proseed has built up the only extensive collection of families (seed from the very best trees surviving in remnant stands across their natural range in Australia) of *E. bosistoana* and *E. argophloia* and it is these families that will be screened for growth-strain. These two premier species have had little investment in growth and form to date, but have immediate appeal (high stiffness, some durability) for LVL. At age 2-3 years, these eucalypts are as stiff as 30 year-old pine, i.e. >8 GPa, and by age 10 they exceed 16 GPa.

E. bosistoana is drought-tolerant, highly ground-durable, intensely-coloured and well able to stand comparison to the finest hardwoods (Millen 2009), *E. argophloia* is also highly durable and closely related to *E. bosistoana* offering the option of hybridisation to increase the genetic diversity in the breeding programme.

E. bosistoana and *E. argophloia* have also been chosen because they coppice easily and propagation from cuttings can be achieved relatively easily (Menzies et al. 2012).

2. Project objectives

The overall objective of this SFF project was to provide the foundations of a new 2nd generation breeding populations of *E. bosistoana* and *E. argophloia* with low growth strain.

A one-year extension to the project enabled the research team to screen two additional durable eucalypt species: *E. quadrangulata* and *E. tricarpa*.

A series of secondary objectives were identified as necessary to achieve the main objective:

1) screen the NZDFI breeding populations at young age for growth-strain and growth
2) establish clonal propagation protocols for cuttings
3) establish breeding population and propagation stock of superior trees/families
4) demonstrate the potential of peeled veneers of a NZDFI species for LVL
5) draw from national and international expertise
6) promote NZDFI species within New Zealand.

3. Trial establishment and harvest

A series of trials were planted on irrigated land at Murray's Nursery, Woodville, Tararua District, in 2015 and 2016 (Figure 3). The seedlings were grown at Morgans Road Nursery, Blenheim, from seed supplied by Proseed. In total more than 19,000 trees from 326 families were included in the trials.

Trees were planted in several batches (Table 1). The scale of this trial was two orders of magnitude larger than any other known breeding programme for growth-strain (Murphy et al. 2005; Naranjo et al. 2012).

Table 1: Summary of trials planted at Murrays Nurseries, Woodville, as part of the SFF 407602 project

Species	**Date planted**	**Date assessed**	**Number of families**	**Number of planted trees**
E. bosistoana	Feb 2015	Nov/Dec 2016	81	4,032
E. bosistoana	Nov 2015	Sep/Oct 2017	68	4,155
E. bosistoana	Feb 2016	Oct 2018	22	2,704
E. argophloia	Feb 2015	Oct 2017	13	336
E. argophloia	Feb 2016	Oct 2018	18	760
E. argophloia	Nov 2016	Dec 2018	9	120
E. quadrangulata	Nov 2016	Jun 2018	83	5,312
E. tricarpa	Nov 2016	Dec 2018	32	1,384
E. sideroxylon	Nov 2016	Dec 2018	seedlot	256
Total			**326 + 1 seedlot**	**19,059**

The trees were also harvested in batches (Figure 4), with the harvested material then transported to the School of Forestry in Christchurch. The trees were assessed for growth-strain using the splitting test (Figures 2, 4) and early growth.

Following harvest, cut stumps were left in the ground and allowed to coppice. This provided the material for cuttings to be taken and transported to Proseed's new propagation facility at Amberley, North Canterbury.

Figure 5: The trials at Murrays Nurseries, Woodville, showing different age material.

Figure 6: Harvesting stems for the splitting (growth strain) test (right).

4. Results

4.1 Screening of durable eucalypt breeding populations for wood properties and early growth

The large-scale testing programme was only possible by making use of the recently developed fast growth-strain assessment, which essentially measures the distortion caused by growth-stress when splitting a stem along the pith (Chauhan & Entwistle 2010; Entwistle et al. 2014) (Figure 2, 4).

Wood properties: overall comparisons

The sampled trees were assessed for the following wood properties:

- growth-strain
- diameter
- density
- acoustic velocity
- volumetric shrinkage
- dynamic modulus of elasticity (MoE).

Summary statistics for the individual species are listed (Table 2). The closely related *E. bosistoana* and *E. argophloia* had very similar wood properties, although *E. argophloia's* growth was considerably slower. Likewise, the closely related and slower growing *E. tricarpa* and *E. sideroxylon* had similar wood properties.

E. bosistoana and *E. argophloia* (~2000 με - measure of growth strain) had higher growth-strain than the other species (~1800 με). This would indicate more distortion after sawing. It is not certain that the higher growth-strain would also translate into more end-splitting, which is relevant for rotary veneer peeling, as this is also affected by wood strength, which can be higher in *E. bosistoana*.

The relatively good performance of *E. quadrangulata* at a young age is interesting. It was the fastest growing species and had the fastest acoustic velocity (i.e. lowest microfibril angle) resulting in high stiffness (12 GPa) at lowest dry density. In comparison, *Pinus radiata* has a stiffness of ~3 GPa at that age. The relatively low volumetric shrinkage of *E. tricarpa* (15%) is also noteworthy.

All the results need to be put into context with properties of wood formed in mature trees. As the cambium ages, wood properties typically become more favourable for human use. It appears that *E. quadrangulata* will not improve to the same extent as *E. bosistoana* with increasing age. For example, Australian old-growth *E. bosistoana* is rated with a MoE of 21 GPa at an air-dry density of 1100 kg/m^3 compared to 18 GPa at an air-dry density of 1030 kg/m^3 for *E. quadrangulata* (Bootle 2005).

Furthermore, *E. bosistoana* has in-ground durability class 1 (>25 years), while *E. quadrangulata* is listed as class 2 (15-25 years). However, if a species is chosen for good mechanical properties at young age (sapwood and corewood) *E. quadrangulata* compares favourably, in particular considering that its sapwood is, in contrast to *E. bosistoana*, not susceptible to lyctids (wood borers) (Bootle 2005).

Table 2: Means of wood properties of five NZDFI eucalypts at age < 3 years old; coefficient of variation (%) in brackets.

Trait	*E. bosistoana*	*E. argophloia*	*E. quadrangulata*	*E. tricarpa*	*E. sideroxylon*
Age (years)	1.7 to 1.9	2.1 to 2.6	1.6	2.1	2.1
Diameter (mm)	36.55 (23.7)	35.58 (27.6)	34.78 (25.4)	23.60 (27.4)	25.71 (21.0)
Growth-strain (με)	2072 (36.4)	2094 (40.9)	1784 (26.3)	1735 (43.7)	1827 (35.1)
Acoustic (km/s)	3.68 (8.2)	3.62 (5.9)	4.42 (4.7)	3.80 (7.2)	3.79 (6.6)
MOEdyn (GPa)	11.16 (17.6)	10.82 (13.5)	12.86 (10.8)	11.35 (15.5)	11.03 (16.1)
Dry density (kg/m^3)	815.8 (5.8)	824.6 (6.7)	655.5 (6.0)	780.3 (5.7)	765 (6.8)
Volumetric shrinkage (%)	20.35 (25.9)	20.40 (18.6)	19.00 (20.7)	15.43 (19.3)	20.01 (16.5)

E. bosistoana: heritabilities of key traits

The heritabilities of the measured traits in *E. bosistoana* are displayed in Table 3 (diagonal).

- Heritabilities for the growth traits under-bark diameter (h^2 = 0.57), and height (h^2 = 0.71) were high, potentially facilitated by the homogenous nursery environment for growth in the trial.
- High heritabilities were also observed for density (h^2 = 0.70), acoustic velocity (h^2 = 0.80) and stiffness (h^2 = 0.77).
- Heritability of volumetric shrinkage was lower (h^2 = 0.39), potentially due to inaccuracies in the green volume data.
- Growth-strain had the lowest heritability (h^2 = 0.23).

The limited accuracy of the 'splitting' test lowered the calculated growth-strain heritability. Another contributing factor might be local variations of form and growth-strain within each stem. While the site was uniform for growth conditions (higher heritability compared to multi-site trials) the local variation in stem form and consequently growth-strain of the young trees might be comparable to that in 'nature'. In any case a heritability of h^2 = 0.23 will allow selecting for low growth-strain, especially considering the wide variation of this trait (coefficient of variation 0.36).

Table 4 also shows the correlations between the assessed traits. Of note are (i) the independence of growth-strain and diameter as well as (ii) the positive correlation between growth-strain and stiffness.

The former means that it is possible to find large trees with low growth-strain. The latter is less favourable as on average lower growth-strain trees will be less stiff. For *E. bosistoana*, however, this is not too problematic as all the trees are of high stiffness. At an age of 21-months the average stiffness was 11.2 GPa, which compares to ~3 GPa for radiata pine at the same age. Results from other *E. bosistoana* plantings are similar.

Table 3: Heritabilities (diagonal, italics) and correlations of E. bosistoana (off diagonal) at age 21-months (81 families).

	Growth-strain	**Diameter**	**Dry density**	**Stiffness**	**Volumetric shrinkage**	**Height**	**Acoustic velocity**
Growth-strain	***0.23***	0.03	-0.14	0.33	-0.16	0.11	0.45
Diameter		***0.57***	-0.25	-0.30	-0.22	0.93	-0.23
Dry density			***0.70***	0.49	0.22	-0.16	0.18
Stiffness				***0.77***	-0.05	-0.15	0.94
Volumetric shrinkage					***0.39***	-0.38	-0.15
Height						***0.71***	-0.08
Acoustic velocity							***0.80***

E. quadrangulata: heritabilities of key traits

The heritabilities of the measured traits in *E. quadrangulata* are displayed in Table 4 (diagonal).

- *E. quadrangulata* growth (diameter) was less heritable than that of the heritability of growth in *E. bosistoana*.
- Heritability of growth-strain in *E. quadrangulata* was approximately twice as high as for *E. bosistoana*. In conjunction with the lower average growth-strain, this suggests that low growth-strain germplasm is easier to achieve for *E. quadrangulata*.
- Volumetric shrinkage was also highly heritable for *E. quadrangulata*. This was possibly related to collapse as there was a stronger negative genetic correlation to dry density, i.e. less dense samples (thinner cell walls) were more likely to collapse. However, the genetic correlation was low.
- Volumetric shrinkage was positively correlated to growth-strain, suggesting that low-strain germplasm also has favourable drying properties.

Table 4: Estimated narrow sense heritability (diagonal, italics) and genetic correlation between average families values (off diagonal) for measured wood traits of 83 E. quadrangulata families aged 19 month. 95% credible intervals in brackets.

Trait	**Diameter**	**Dry density**	**Acoustic velocity**	**Volumetric shrinkage**	**Stiffness**	**Growth-strain**
Diameter	***0.20*** ***(0.10, 0.31)***	-0.19 (-0.8, 0.07)	0.13 (-0.2, 0.46)	0.28 (-0.04, 0.49)	0.03 (-0.30, 0.36)	0.07 (-0.20 ,0.35)
Dry density		***0.37*** ***(0.18 , 0.54)***	0.38 (0.07, 0.49)	-0.18 (-0.29, -0.41)	0.68 (0.34, 0.98)	0.12 (-0.27, 0.42)
Acoustic velocity			***0.67*** ***(0.46 , 0.85)***	0.27 (0.01, 0.49)	0.94 (0.56, 136)	0.35 (0.06, 0.54)
Volumetric shrinkage				***0.92*** ***(0.59 , 1.2)***	0.14 (0.08, 0.16)	0.49 (-0.14, 0.54)
Stiffness					***0.79*** ***(0.53 , 1.0)***	0.32 (0.12, 0.43)
Growth-strain						***0.40*** ***(0.26 , 0.56)***

Note: As for the previous *E. bosistoana* analysed trials, some values were exceeding the theoretical maximum of 1. This can be explained by the lacking information on relatedness within and between the assumed half-sibling families.

4.2 Selection of superior genotypes

The initial strategy for selecting a superior low growth-strain landrace was to choose the best individuals from all families to ensure broad genetic diversity for further selections for additional traits – for example, tree health and heartwood.

The following strategy was applied for the first and second *E. bosistoana* trials: selecting the top three growth-strain and diameter individuals in each family as well as the two with lowest density, the stiffest, tallest, and the two with the fastest acoustic velocity. To achieve the targeted number of individuals, trees (around 1 in 3) were selected using a technique called global index section, weighting diameter and growth equally. Only trees above 25 mm diameter and below 3000 µstrain were considered. The distribution of selections within the population can be seen below (Figure 5).

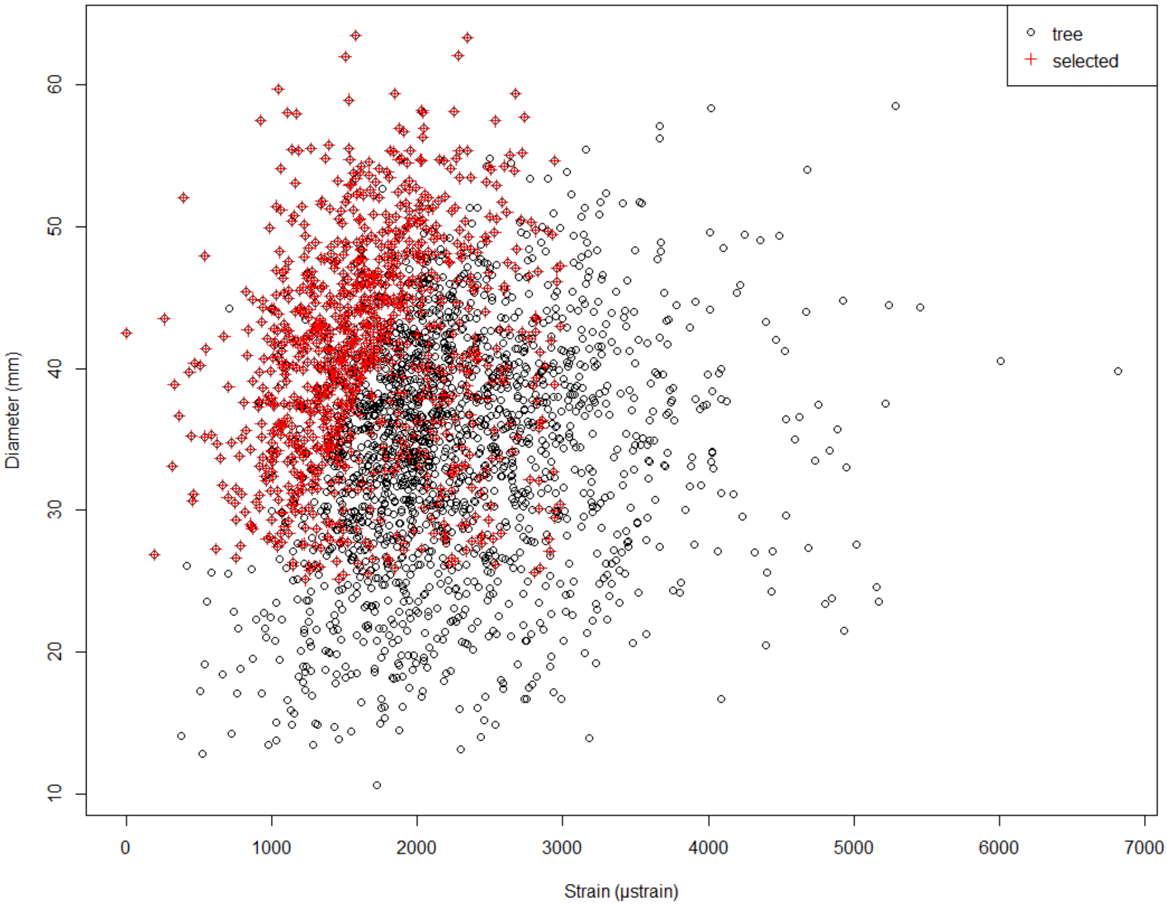


Figure 5: Growth-strain versus diameter for 4032 E. bosistoana *trees from 81 families at age ~21 month. The 1000 selected individuals are marked with red crosses.*

However, during the course of this project it was realised, that due to the low precision of the destructive ‘splitting test’ caused by the inhomogeneous stress field in the stems, only accurate estimates of family means could be obtained. Therefore, the selection strategy needed to be changed, and we moved to selecting superior families rather than individuals. As a consequence, the genetic diversity of the 2nd generation breeding population will be reduced. The selection of 1st generation top material for clonal production is not affected.

Learning from these findings, the *E. quadrangulata* families (not individuals) with below average growth-strain and above average early growth (Figure 6, top left quadrant) were selected for propagation and coppice was taken from any surviving plant in the trial. A selection intensity of 1 in 4 (21 of 83 families) is low compared to other breeding programmes. The genetic gains were therefore limited (Table 5) but conserved a broader genetic base, allowing future selection for other traits like tree health and heartwood. The magnitude of growth-strain reduction was ~300 με, comparable to that of *E. bosistoana*.

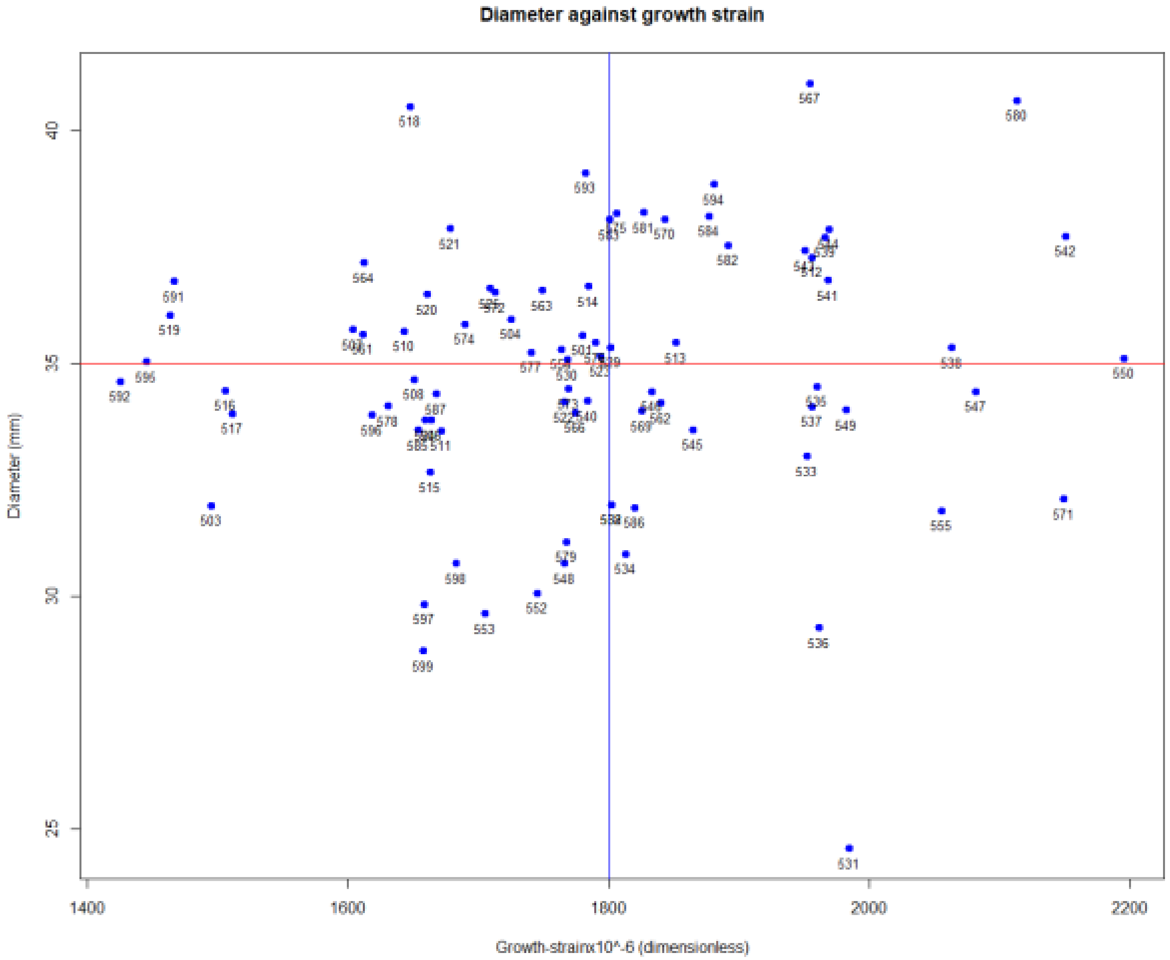


Figure 6: Relationship between family averages for diameter and growth-strain of E. quadrangulata *aged 19 months. Blue and red lines depict average growth-strain and diameter, respectively.*

Table 5: Genetic gains for the assessed traits of E. quadrangulata *aged 19 month depending on selection intensity. Each trait was considered individually.*

Selection intensity	**1%**	**5%**	**10%**	**20%**	**25%**
Growth-strain (με)	-556 (32.2)	-523 (29.3)	-465 (26.1)	-341 (19.1)	-313 (17.5)
Stiffness (GPa)	2.79 (21.7)	2.49 (19.4)	2.07 (16.1)	1.59 (12.4)	1.44 (11.2)
Acoustic velocity (km/s)	0.44 (10.0)	0.33 (7.5)	0.28 (6.3)	0.21 (4.8)	0.19 (4.3)
Volumetric shrinkage (%)	-6.64 (34.9)	-5.78 (30.4)	-5.30 (27.9)	-4.46 (23.5)	-4.11 (21.6)
Dry density (kg/m³)	57.9 (8.8)	39.8 (6.1)	34.1 (5.2)	26.5 (4.0)	23.8 (3.6)
Diameter (mm)	6.79 (19.5)	6.10 (17.5)	5.05 (14.5)	4.12 (11.8)	3.78 (10.9)

4.3 Propagation

Clonal propagation was critical for this project, because we wanted to ‘rescue’ superior individuals after destructive growth-strain testing. Clonal propagation is also essential for a timely commercial deployment of large numbers of superior plant material to establish forestry plantations.

At the start of this SFF 407602 project, virtually no expertise existed in propagating the NZDFI durable eucalyptus species (i.e. *E. bosistoana*, *E. argophloia*, *E. quadrangulata* and *E. tricarpa*) from coppice shoots. While clonal propagation from coppice shoots is conducted on other species at a commercial scale overseas, it is not practised in New Zealand as none of the eucalypt species grown on a relatively large scale in New Zealand can be propagated in this way.

Proseed (Amberley, NZ) took on the propagation challenge for the durable eucalypts and developed a propagation protocol in this programme with the help of national and international propagation experts via a series of workshops.

Proseed staff visited to Narrowmine Nurseries (Australia), allowing them to gain experience with commercial clonal propagation of eucalypts. The propagation protocol introduced at Proseed following these visits has been continuously improved, and as a result Proseed has been able to propagate the targeted number of plants for the SFF 407602 project (Figure 7). With its investment in a new propagation facility, Proseed is now set up to further develop commercial scale clonal propagation of improved durable eucalypt material.

Figure 7: Rooted E. bosistoana cuttings (left). Stool material of superior genetics (right).

Over the past three seasons, over 25,000 cuttings were set, resulting in over 10,000 plants being potted (Table 6). More than 1,000 *E. bosistoana* clones selected for early growth and low growth-strain were captured. This is a great success in light of international experience. For example in Brazil and South Africa only 2-5% of original *E. grandis* and hybrid genotypes pass all selection criteria. 70-80% of genotypes may fail on propagation ability alone.

Clonal propagation of the first improved *E. argophloia* and *E. quadrangulata* genotypes has also been successful.

Table 6: Overview of the propagation effort under the SFF 407602 project.

Species	Set cuttings	Set clones	Captured clones
E. bosistoana 2016	11,300	696	532 (228 > 5 individuals)
E. bosistoana 2017	13,206	642	616 (505 > 5 individuals)
E. argophloia 2017	500	16	13
E. quadrangulata 2018	1729	129	75 (32 > 5 individuals)

E. bosistoana clones from the top performing families (including not only growth-strain assessments from this SFF 407602 project, but also their performance in other NZDFI breeding trials for form, growth and heartwood) are now established as stool material for commercial clonal propagation (Figure 7).

The *E. bosistoana* clones produced have now been established in two low growth-strain clonal breeding trials (Table 7, Figure 8). This was financed independently by NZDFI.

Table 7: E. bosistoana clonal trials established in 2018.

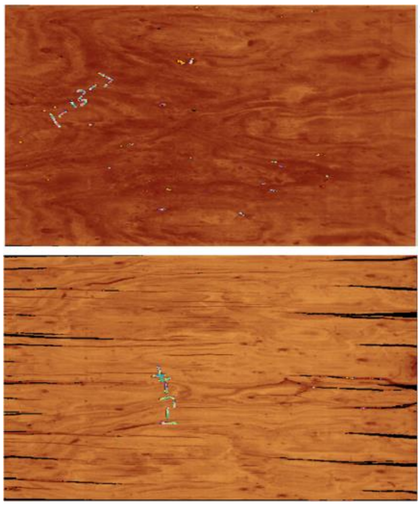
	Northbank	Dillons
Block Size	25 trees, 1274 sph	25 trees, 1274 sph
No. Blocks	99	25
No. clones	619	138
No. families	133	74
No. cuttings per clone	Mean = 4, Range 3-8	Mean = 4, Range 3-8

Figure 8: Planting of Eucalyptus bosistoana clones selected for low growth-strain at the Northbank breeding trial.

4.4 Veneer peeling / laminated veneer lumber (LVL)

A peeling trial in a commercial production setting of 26 *E. globoidea* logs from nine 30-year-old trees was conducted by Nelson Pine Industries Ltd (Guo & Altaner 2018).

The peeling trial demonstrated that veneers of suitable quality could be obtained from these logs (Figure 9a) Yields were highly variable between the trees and negatively correlated to growth-strain, indicating the usefulness of selecting low growth-strain genetics for the establishment of a durable eucalypt industry (Figure 9b).



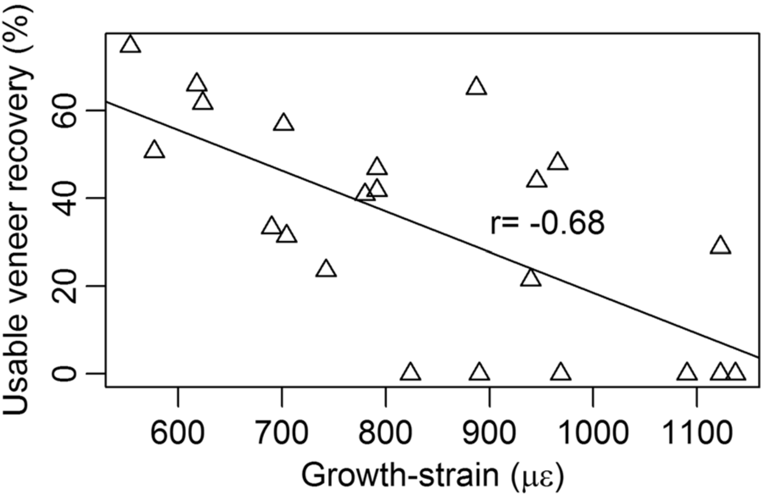


Figure 9a (Left): Face grade veneer with no splitting (top) and composer grade veneer with severe splitting (bottom).

Fig 9b (Right): Dependence of usable veneer conversions on growth-strain of the individual E. globoidea logs. From (Guo & Altaner 2018).

The veneers produced were used to manufacture high MoE grade LVL. This work highlighted difficulties in achieving well performing bonding between the *E. globoidea* veneers, when using radiata parameters (Table 8). However, subsequent work outside this SFF 407602 programme with the remaining veneers indicated that this issue can be solved by optimising press parameters (Kropat 2018).

Table 8: Bond tests of six LVL panels made from E. globoidea. From (Guo & Altaner 2018)

Grade (GPa)	Density (g/cm^3)	Steam test			Immersion test		
		EE_{min}	EE_{max}	EE_{mean}	EE_{min}	EE_{max}	EE_{mean}
12	640.51	1	9	5	1	5	2
16	696.92	3	8	6	4	9	6
16	702.52	1	9	6	3	8	7
16	806.83	0	5	1	0	3	2
14	809.22	0	3	2	2	3	2
17.5	860.05	1	4	2	0	7	3

EE represents bond quality values between *E. globoidea* veneers (0 no bond – 10 excellent bond). The minimum, maximum and mean values are shown

This work is now continued under the MBIE Speciality Wood Products (SWP) Research Partnership, where it was recently shown that good quality veneers could also be produced form 15-year-old *E. bosistoana* and *E. quadrangulata* logs. Ongoing work is the confirmation of suitable gluing process parameters and the economic evaluation of durable eucalypts for peeling.

5. Outreach/communication outcomes from SFF 407602

5.1 Workshops

Four workshops with international participation were supported by this SFF 407602 programme:

1. International workshop, University of Canterbury, September 3rd & 4th 2015

A workshop to outline the best approach to propagate the superior (low growth-strain) trees was held at the University of Canterbury. The workshop included a field trip to the Harewood trial site and two tree nurseries. The invited (domestic and international) experts gave advice on the suitability of the facilities and methodology.

2. Meeting, University of Canterbury, March 30th 2016

A catch-up meeting of the propagation team. Results of the initiated propagation trials were discussed and the timing of the Woodville harvest was planned.

3. International workshop, Blenheim, 19th & 20th of April 2017

The main aims of this workshop were a) to inform our supporters and the wider public of the recent progress in establishing a forest industry based on durable eucalypts and b) to review our research programme by international experts. The workshop was attended by approximately 60 people including participants from Australia, Sweden, Austria, China and Japan. Video recordings of the workshop presentations and other material is available online at http://nzdfi.org.nz/news-and-events/resources/workshop-durable-eucalypts-protecting-and-enhancing-value/ and was published in proceedings (Altaner et al. 2017). The workshop included a field trip to a local NZDFI breeding trial site and to Nelson Pine Industries plant in Richmond.

4. International workshop, University of Canterbury, June 19th 2018

A further workshop was held to present and discuss the outcomes of the past three years' work under the SFF 407602 project. This workshop was promoted throughout the domestic forestry sector and also gained Australian and Japanese interest. The workshop was attended in person or by video conference by the majority of the co-funders acting as the advisory board. Options on how to further increase the uptake of durable eucalypts in the NZ forestry sector were discussed.

The work has been promoted at various industry events, for example:

- The New Zealand Forest Nursery Growers Association (April 15th 2016)
- Forest Growers Research Conference (October 19th 2017)
- Solid Wood Products (SWP) Partnership TST meeting (February 19th 2018)

In addition, the project has featured on the NZDFI website (www.nzdfi.org.nz), and has been regularly reported on in the NZDFI's biannual Project Updates (https://nzdfi.org.nz/news-and-events/resources/project-updates/).

5.2 Publications

1. Schroeder, P., & Altaner, C. (2016). Propagation - a bottleneck in tree breeding programmes? New Zealand Tree Grower, November, 35-36.
2. Altaner, C., Murray, T.J., & Morgenroth, J. (Eds.). (2017). Durable Eucalypts on Drylands: Protecting and Enhancing Value. Christchurch, NZ: New Zealand School of Forestry. 123pp
3. Guo, F., & Altaner, C.M. (2018). Properties of rotary peeled veneer and laminated veneer lumber (LVL) from New Zealand grown *Eucalyptus globoidea*. New Zealand Journal of Forestry Science, 48(1), 3. doi: 10.1186/s40490-018-0109-7
4. Millen, P., van Ballekom, S., Altaner, C., Apiolaza, L., Mason, E., McConnochie, R., Morgenroth, J., & Murray, T. (2018). Durable eucalypt forests – a multi-regional opportunity for investment in New Zealand drylands. New Zealand Journal of Forestry, 63, 11-23.

5.3 Student theses

A large part of the work in this SFF 407602 project was conducted by students. Over the four years of the project over 30 under- and postgraduate students participated in trial maintenance, tree harvesting and wood properties measurements, exposing them to an alternative forestry option to *P. radiata* (Appendix 1, Table 2). More importantly, the project also fully or partly supported three PhD (Nick Davies, Fei Guo, Ebenezer Iyiola) and one BForSci (hon) (Lisa Nguyen) theses, ensuring future foresters and researches having expertise in durable heartwood forestry.

Theses including work originating from the SFF 407602 project:

1. Fei Guo (2019 – PhD thesis) 'Molecular deformation of wood and cellulose studied by near infrared and Raman spectroscopy'. https://ir.canterbury.ac.nz/handle/10092/16781.
2. Nick Davies (2019 – PhD thesis to be submitted) 'High throughput breeding for wood quality improvement'.
3. Lisa Nguyen (2019 – BForSci (hon) thesis to be submitted) 'Genetic control of wood properties in *Eucalyptus tricarpa* at age 2'.
4. Ebenezer Iyiola (2020 – PhD thesis to be submitted) 'Wood quality of durable eucalypts'.

5.4 Industry involvement

The involvement of nurseries, forest contractors, growers, wood processors and public research funders has achieved industry awareness and uptake, and contributed to continuation of the NZDFI's durable eucalypt programme.

6. Conclusion

This project was embedded in a larger effort aiming to establish a sustainable durable timber resource in New Zealand (www.nzdfi.org.nz). The outcomes of this SFF 407602 project achieved key requirements for this goal:

- Superior genotypes with lower growth-strain have been identified and will soon be made commercially available through clonal propagation from coppice.
- The potential and the main obstacles (i.e. gluing) of a NZDFI species for LVL production has been demonstrated.
- Other essential areas for the NZDFI project like growth and yield modelling, forest health, breeding for other traits (e.g. form and durability) or economic models are worked on through aligned projects; currently the most significant being the MBIE Speciality Wood Products (SWP) Partnership (https://fgr.nz/wp-content/uploads/2018/04/SWP-Programme-Description.pdf).

7. References

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Appendix 1: Students involved in SFF 407602

Table 2: List of directly employed under- and post graduate students involved in this SFF 407602 project

	Name
1	Yannina Whitely
2	Yanjie Li
3	Thornton Campbell
4	Seoljong Kim
5	Ryan van Handel
6	Rhys Black
7	Nick Davies
8	Nick Barry
9	Morgan Scragg
10	Mike Pay
11	Marlene Cramer
12	Manuel Morena
13	Lisa Nguyen
14	Kigwang Baek
15	Joshua Foster
16	Josh Irvine
17	James Govina
18	Jack Burgess
19	Gracie Perkins
20	Francis Obi
21	Fei Guo
22	Ebenezer Iyiola
23	Darius Phiri
24	Daniel Debrah
25	Daniel Boczniewicz
26	Chamira Rajapaksha
27	Boris van Bruchem
28	Arthuro Bascunan
29	Ansen Chen
30	Anne Wekesa
31	Ahmad Karsidi