SFF 407602 Minimising growth-strain in Eucalypts to transform processing

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The objectives of this project were to:

1) screen the NZDFI breeding populations at young age for growth-strain and growth
2) establish clonal propagation protocols from 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

The following entities collaborated in this project, which started in July 2015:

- Proseed
- Nelson Pine Industries Ltd
- Juken NZ
- Timberlands
- Ernslaw One
- Marlborough Lines
- Vineyard Timbers
- Murrays Nurseries
- Forest Growers Levy Trust
- University of Canterbury
- NZDFI

Overall, the project was successful, making progress in all objectives and on time. In more detail:

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

Trees were planted and harvested in several batches at Murrays Nurseries, Woodville (Table 1). In total more than 19,000 trees from 326 families were included in the trials. The breeding populations of four of the five species selected by NZDFI were assessed for growth-strain and early growth. 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). This 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).

Table 1: Summary of trials planted at Murrays Nurseries, Woodville, as part of the SFF407602 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**

<u>*Wood properties*</u>

Apart from growth-strain and diameter, density, volumetric shrinkage and dynamic modulus of elasticity (MoE) were assessed on the sampled trees. Summary statistics for the individual trials are listed in (Table 1). The closely related *E. bosistoana* and *E. argophloia* had very similar wood properties, although *E. argophloia* was growing considerably slower. Likewise, the closely related slower growing *E. tricarpa* and *E. sideroxylon* had similar wood properties. *E. bosistoana*/*E. argophloia* (~2000 με) 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 in more end-splitting, what is relevant for rotary veneer peeling, as this is also affected by wood strength, which can be higher in *E. bosistoana*. Of interest is the good performance of *E. quadrangulata* at young age. 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. It should be remembered that *Pinus radiata* has a stiffness of ~3 GPa at that age. Noteworthy is also the relatively low volumetric shrinkage of *E. tricarpa* (15%).

This needs to be put in context with properties of wood formed by mature trees. As the cambium ages wood properties typically become more favourable for human use and it appears that *E. quadrangulata* will not improve to the same extent as *E. bosistoana* at maturity. 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 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)	<u>4.42 (4.7)</u>	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)	<u>15.43 (19.3)</u>	20.01 (16.5)

<u>*E. bosistoana*</u>

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 (Table 3). 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 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 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 3 also shows the correlations between the assessed traits. To note are the independence of growth-strain and diameter as well as 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 more unfavourable as in average lower growth-strain trees will be less stiff. For *E. bosistoana*, however, this is not too problematic as 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 of the other *E. bosistoana* plantings were similar.

Table 3: Heritabilities (diagonal, italics) and correlations (off-diagonal) of E. bosistoana 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

The heritabilities of the measured traits in *E. quadrangulata* are displayed in Table 4 (diagonal). Compared to heritabilities obtained for *E. bosistoana* in this SFF program, growth (diameter) was less heritable. However, the heritability of growth-strain was found to be approximately twice as high for *E. quadrangulata*. In conjunction with the lower average growth-strain, this suggested that low growth-strain germplasm is easier to achieve for *E. quadrangulata*. It is worth noting that 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*	-0.19	0.13	0.28	0.03	0.07
	(0.10, 0.31)	(-0.8, 0.07)	(-0.2, 0.46)	(-0.04, 0.49)	(-0.30, 0.36)	(-0.20 ,0.35)
Dry density		*0.37*	0.38	-0.18	0.68	0.12
		(0.18 , 0.54)	(0.07, 0.49)	(-0.29, -0.41)	(0.34, 0.98)	(-0.27, 0.42)
Acoustic velocity			*0.67*	0.27	0.94	0.35
			(0.46 , 0.85)	(0.01, 0.49)	(0.56, 136)	(0.06, 0.54)
Volumetric shrinkage				*0.92*	0.14	0.49
				(0.59 , 1.2)	(0.08, 0.16)	(-0.14, 0.54)
Stiffness					*0.79*	0.32
					(0.53 , 1.0)	(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.

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 like tree health and heartwood. This strategy was followed for the first and second *E. bosistoana* trial, selecting in each family the top 3 strain and diameter individuals as well as the 2 with lowest density, the stiffest, tallest, and that with the fastest acoustic velocity. To achieve the targeted number of individuals trees (~1/3) were selected by global index section weighing 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 in (Figure 1).

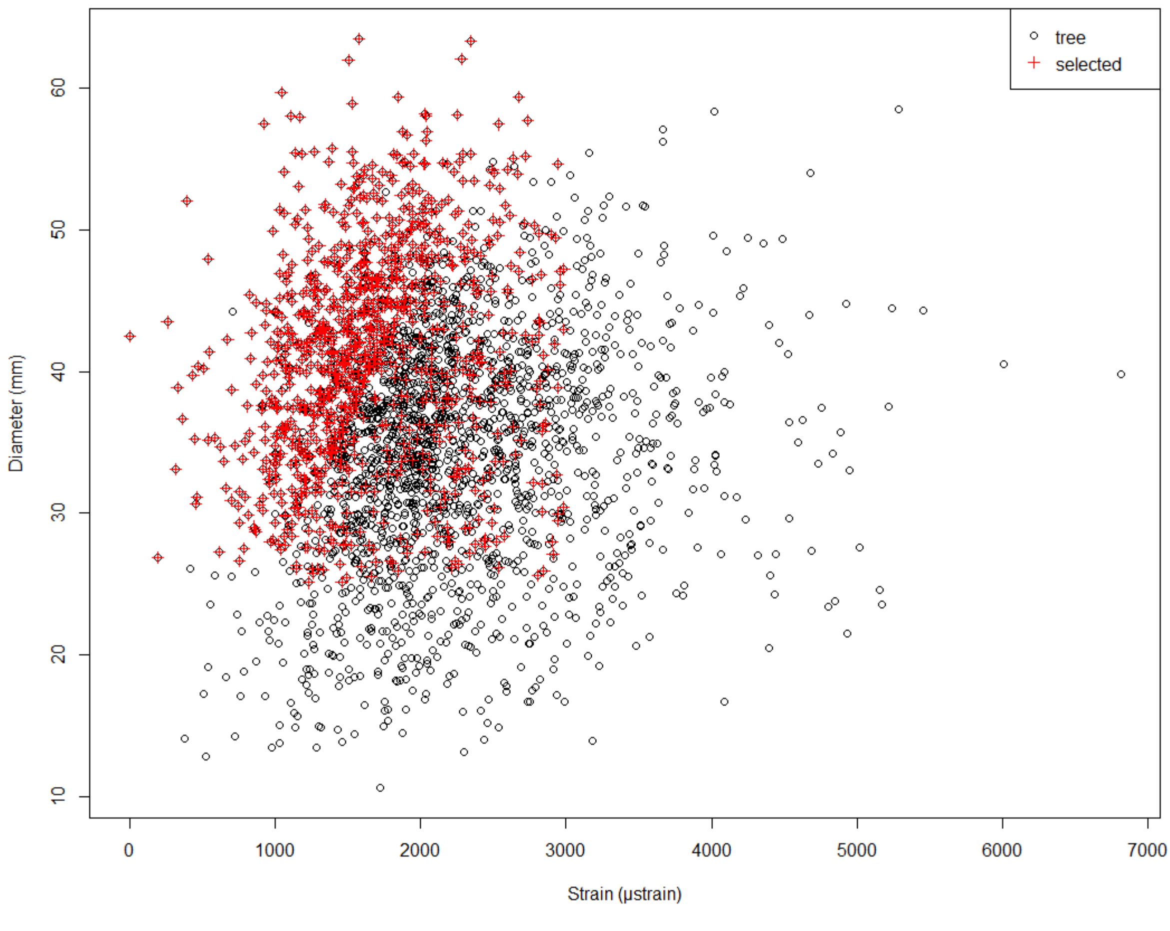

Figure 1: Growth-strain versus diameter for 4032 E. bosistoana trees from 81 families at age ~21 month. The 1000 selected individuals are marked with red crosses.

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 can be obtained. Therefore, the selection strategy needs to be changed, 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 2, 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 programs. 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* under the same selection strategy.

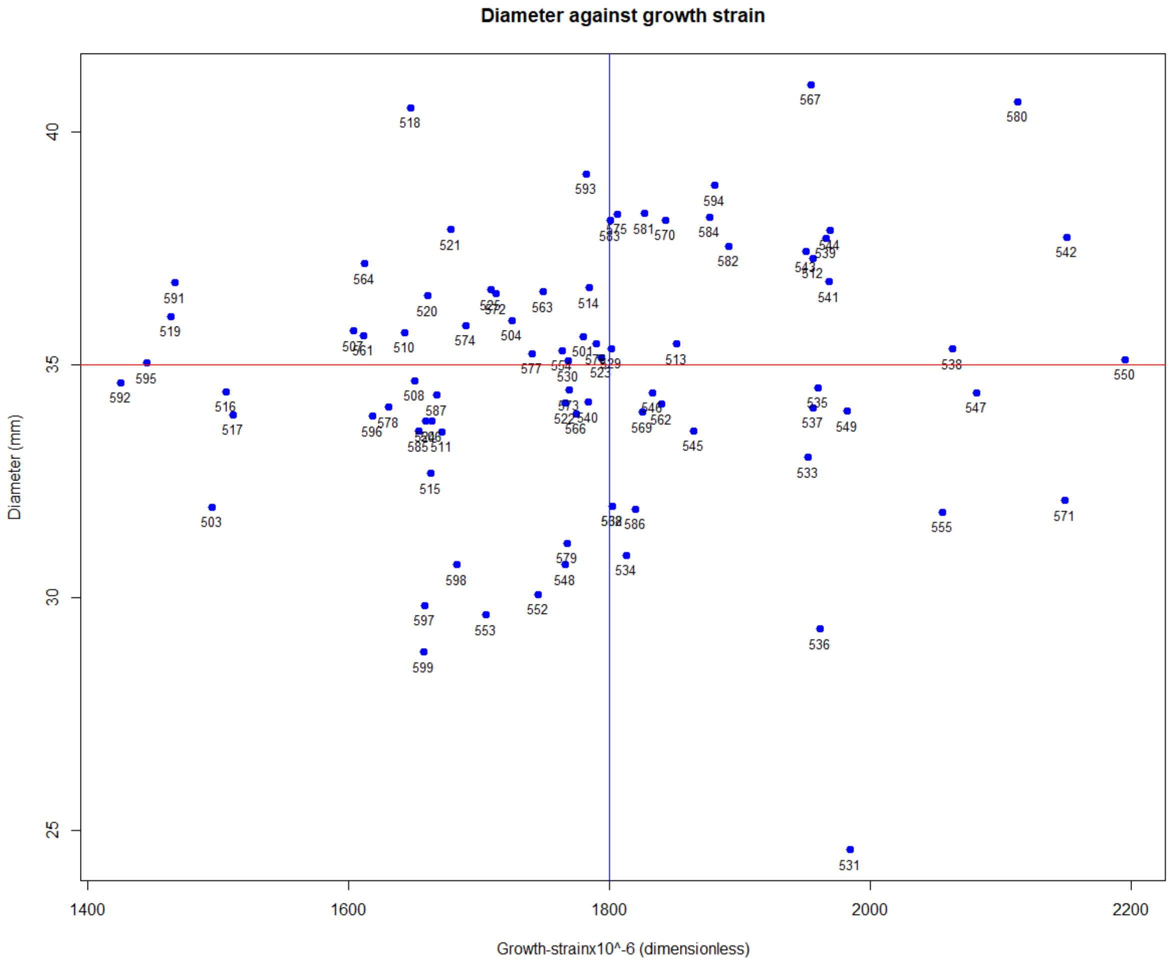

Figure 2: Relationship between family averages for diameter and growth-strain of E. quadrangulata aged 19 month. Blue and red lines depict average growth-strain and diameter, respectively.

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/m^3)	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)

2) Propagation

Clonal propagation was not only critical for this project, as it intended to rescue superior individuals after destructive growth-strain testing, but is also essential for a timely deployment of superior plant material to establish commercial forestry plantations. At the start of this SFF407602 project virtually no expertise exited on propagating the NZDFI durable eucalyptus species (i.e. *E. bosistoana*, *E. argophloia*, *E. quadrangulata* and *E. tricarpa*) from coppice shoots. Furthermore, while clonal propagation from coppice shoots is conducted on a commercial scale in other countries, it is not practised in New Zealand as no commercial eucalypt species grown 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 in workshops. Staff visits to Narrowmine Nurseries (Australia) allowed them to gain experience with commercial clonal propagation of eucalypts. The propagation protocol has been constantly optimised and was able to propagate the targeted number of plants for the SFF407602 project (Figure 3). 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 3: Rooted E. bosistoana cuttings (left). Stool material of superior genetics (right).

Over the last 3 seasons >25000 cuttings were set resulting in >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 SFF407602 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 preforming families (including not only growth-strain assessments from this SFF407602 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 3). Furthermore, the produced *E. bosistoana* clones have now been established in two low growth-strain clonal breeding trials (Table 7, Figure 4). 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 4: Planting of Eucalyptus bosistoana clones selected for low growth-strain at the Northbank breeding trial.

3) 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 NPI Ltd (Guo & Altaner 2018). The peeling trial demonstrated that veneers of suitable quality could be obtained from these logs (Figure 5). 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 5).

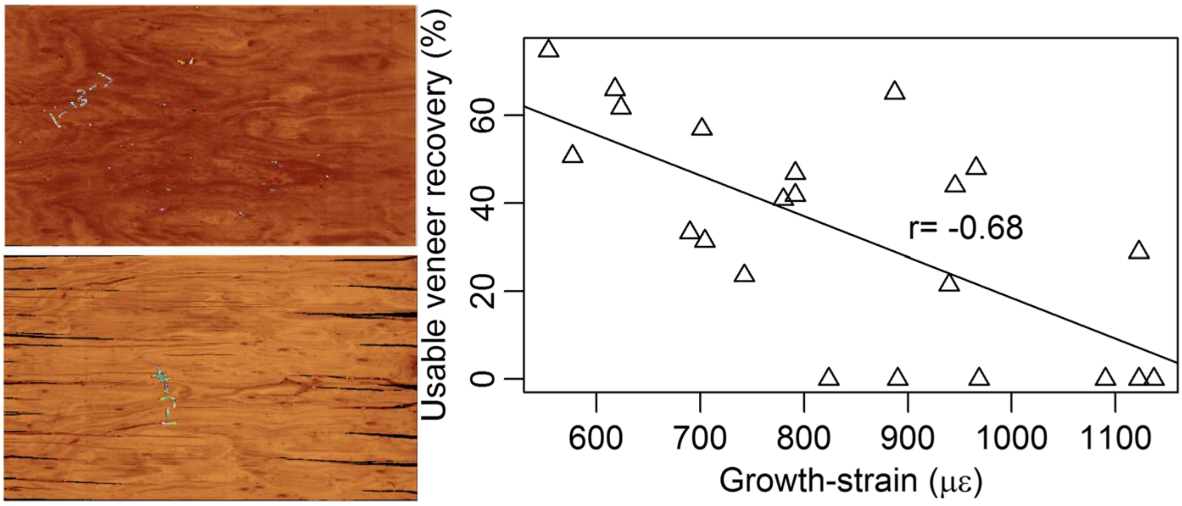

Figure 5 Left: Face grade veneer with no splitting (top) and composer grade veneer with severe splitting (bottom). Right: Dependence of usable veneer conversions on growth-strain of the individual E. globoidea logs. From (Guo & Altaner 2018).

Furthermore, the veneers 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 SFF407602 program 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) 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.

4) Outreach

Four workshops with international participation have been supported by this SFF407602 programme.

1. 3rd & 4th of September 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 2 tree nurseries. The invited (domestic and international) experts gave advice on the suitability of the facilities and methodology.
2. 30th of March 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. 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. 19th of June 2018
   Workshop presenting and discussing the outcomes of the work of the last 3 years under this SFF407602 project. This workshop was promoted throughout the domestic forestry sector and gained also 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 occasions, for example:

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

Publications resulting from SFF407602 project are:

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.

A large part of the work in this SFF407602 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* (Table 9). 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. The involvement of nurseries, forest contractors, growers, wood processors and public research funders achieved industry uptake and continuation of the durable eucalypt program.

Theses including work originating from the SFF407602 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'

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 SFF407602 project achieved key requirements for this goal. Superior genotypes with lower growth-strain have been identified and are now 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).

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Appendix

Table 9: List of directly employed under- and post graduate students involved in this SFF407602 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