Specialty Wood Products Research Partnership

MARLBOROUGH RESEARCH CENTRE
Te Rito Hiranga o Wairau

Variation in adaptability and productivity between durable eucalypt species in different New Zealand environments.

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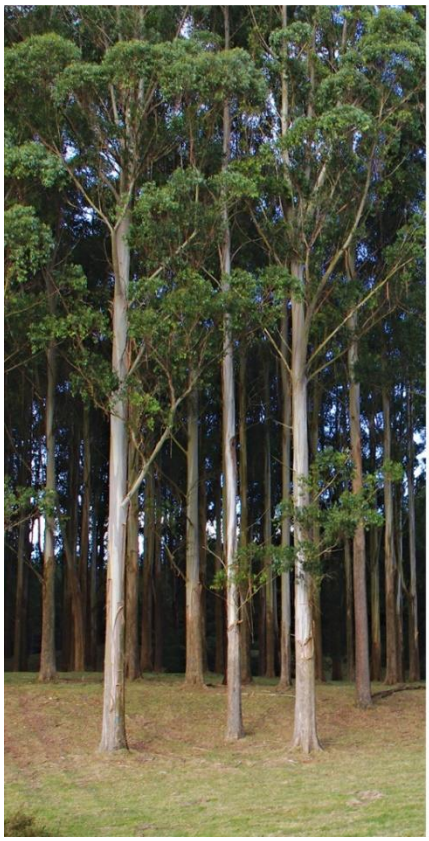

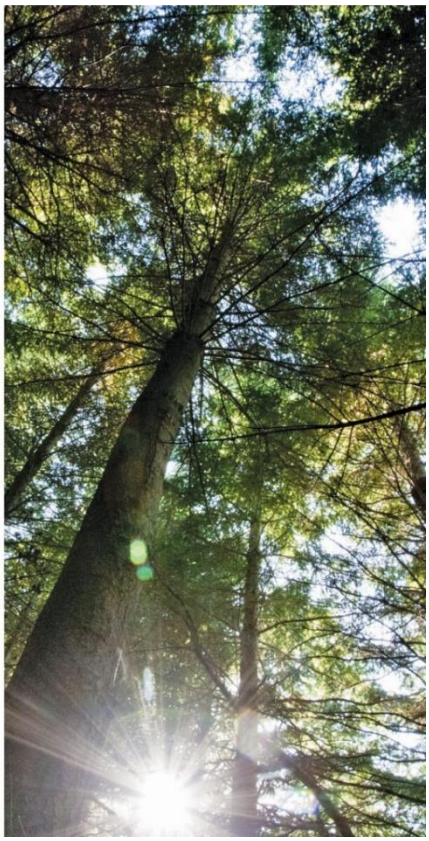

Date: July 2023

Publication No: SWP-T164

PUBLIC REPORT INFORMATION SHEET

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EXECUTIVE SUMMARY

This report summarises early results from a total of 14 demonstration trials implemented by the NZDFI established across North Island regions and those in Marlborough, Nelson and North Canterbury.

The trials evaluated variation in tree survival, growth and stem of eleven eucalypt species. The species are reported in three groupings: class 1 brown heartwood, class 2 and 3 brown heartwood and class 1 and 2 red heartwood. Assessments made at ages ranging from seven to eleven years are reported. For each species, the relative performance of the seed sources across different trial site and climatic factors is given, showing the degree of G x E (genotype by environment interaction), which is important when choosing species for planting.

Prior information on growth rates of these eucalypt species is very limited, so the data reported here will enable prospective growers to obtain a better idea of the performance that can be expected from well-managed plantations, and the degree of improvement obtainable from selecting the right species and seed sources.

INTRODUCTION

Background

New Zealand Dryland Forests Innovation[1] (NZDFI) was established as a public/private collaborative initiative in 2008. Its aim was to undertake tree breeding and forestry research to develop genetically improved drought-tolerant eucalypts that produce high-quality naturally ground-durable hardwood. NZDFI have developed a vision for a sustainable durable hardwood industry based on a total of 60,000 hectares of eucalypt forests being established in twelve regional wood-supply catchments centred around future processing hubs (5,000 hectares per catchment) by 2050. Our focus started in geographic regions with less than 1000 mm/yr average rainfall and where a new hardwood forestry option could diversify regional economic development. See Our vision - NZ Dryland Forests Innovation (nzdfi.org.nz)

NZDFI's unique research focus and strategic vision is to deliver improved plants and forestry knowledge to enable growers to select and grow eucalypt species suited to their site. This will enable a new forestry investment opportunity that will diversify Aotearoa New Zealand's future wood supply – that is, to grow eucalypts that will produce high-quality durable timber that meets the requirements of domestic and international markets.

New-Zealand-grown durable hardwood could substitute hardwood imports, substitute copper-chrome-arsenate (CCA) -treated products, be a component of engineered wood products, and produce high-value export products that are a sustainable alternative to unsustainably logged tropical hardwoods.

Much of the demand for durable hardwood is currently supplied from illegal/unsustainable sources. There are international efforts to combat illegal timber trade and consumers are demanding sustainable supply. The New Zealand Government has passed the Forests (Legal Harvest Assurance) Amendment Bill to stop the import of illegally harvested timber and to provide legal harvest assurance for all New Zealand exported timbers which will bring it in line with Australia, EU countries and the USA, all of which have laws requiring wood imports are from legal sources.

The early European settlers of New Zealand imported both seed to grow eucalypts and eucalypt hardwood for housing and construction. The original Treaty House at Waitangi was built in 1840 using *Eucalyptus saligna* framing timber and clad with *E.resinifera* weather boards. We know that naturally durable hardwood can provide a long service life. Many eucalypt species are well adapted to New Zealand environments and there are trees of a diversity of species now over 150 years old and still growing. New Zealand has a long history of innovative eucalypt growers successfully testing species for forestry with some of these researched and developed for large-scale planting.

Many forest growers and farm foresters want to diversify and sustainable durable eucalypt forestry is an option for many in North Island regions and those in Marlborough, Nelson and North Canterbury.

Eucalypt species that produce durable heartwood evolved across a wide range of diverse environments. It is in the temperate regions of south-eastern Australia i.e New South Wales and Victoria where the geographic influence of the Great Dividing Range creates environments with some similar to New Zealand.

New Zealand is a much smaller country with very diverse regional and local environments. Therefore, selecting a group of species with broad adaptability and productive growth and carefully **matching species to site and to end-products** is important to success.

[1] The organisation was called NZ Dryland Forests Initiative until 2023

NZDFI identified species with proven adaptability or potential adaptability for New Zealand's warmer and drier regions, and with proven timber durability for high value products and diverse applications.

The species selected for tree improvement have been commercially sawn and processed in Australia with some of these widespread in their natural range, and others with limited distribution. Some are considered endangered and are no longer commercially available. The unavailability of 'native hardwood' in Australia will significantly increase with the West Australian Government ending the harvest of jarrah forests and the Victorian Government ending the harvest of mixed eucalypt forests in 2024. This presents a huge market opportunity for New Zealand forestry.

METHODS

Species selection for demonstration trials

In 2008, the selection of species for NZDFI's research programme was guided by:

- proven or potential adaptability of the species to New Zealand environments, as cited in New Zealand literature
- experience shared by many New Zealand durable eucalypt growers
- commercial use and proven durability of their hardwood in both Australian and New Zealand literature.

Selection criteria took into account species' potential for commercial plantation use and included:

- fast growth
- stem form (straightness)
- drought and frost tolerance
- pest tolerance
- early durable heartwood formation and timber colour
- vigorous coppice
- good nectar/pollen production for native biodiversity and bees.

Species selection was informed by research conducted over many years by the Special Purpose Species Group of Scion and the Eucalypt Action Group of the NZFFA; also by trials established in a collaboration between Vineyard Timbers, the Marlborough District Council, Proseed NZ Ltd and several private landowners in Marlborough prior to 2008.

A total of 11 species were selected for testing including several species that had not been previously tested in New Zealand but offered potential based on Australian experience.

It is commonly known that eucalypts can be site specific and perform very differently depending on site conditions. There can be large variation within a species, with some exhibiting highly productive growth on favourable sites and unproductive growth or total failure on other sites. The demonstration trials were established with broad-based seedlots to test each specie's adaptability across a wide range of New Zealand dryland (and in some cases high rainfall) environments.

NZDFI selected three key species as the main focus for tree improvement:

- *E. bosistoana*
- *E. globoidea*
- *E. quadrangulata.*

Two additional minor species were included in the breeding programme, *E. argophloia* and *E. tricarpa*.

These five species were established in the NZDFI's network of demonstration trials in 2011 along with a further six species selected for testing and evaluation:

- *E. camaldulensis*
- *E. cladocalyx*
- *E. eugenioides*
- *E. longifolia*
- *E. macrorhyncha*
- *E. notabilis.*

One set of trials planted in 2011 includes all 11 species. Fewer species were included in 2010 trials (4 species), and in 2012 (7 species), 2013 (6 species), 2014 (8 species) and 2018 (6 species).

Wood properties of selected species

While all the selected NZDFI species produce durable heartwood, each species has distinct wood properties, suitable for different applications.

The two main wood properties that influence the potential applications and therefore the market value and demand for the hardwood produced by these species are heartwood durability and colour.

Coloured durable heartwood associated with tropical species, such as teak and rosewood, is highly sought after and valued by international markets. Demand in New Zealand is no different, with highly priced imports of class 1 durable hardwood timbers coming from natural forests growing in Australia, the Pacific, SE Asia, the Americas or Africa. These include regular tropical timber imports of purpleheart (South America), balau (Malaysia), iroko (Africa) and ironbark (Australia).

Class 2 durable hardwood timbers are also imported and attract a premium price in New Zealand markets. These include jarrah (Australia) and kwila (Malaysia), and American and European oak. New Zealand-grown sustainably managed beech is a local alternative.

Some durable eucalypt species are renowned for their rich, dark timber and these could substitute hardwood imports and be marketed under a New Zealand-grown brand.

Table 1 presents the botanical name, common name, durability classifications (ref: Australian Standard AS 5604) and colour for all species established in NZDFI trials. These have been grouped under their timber colour being either principally brown or red.

Table 1: NZDFI demonstration trial species, common name, natural durability classification and heartwood colour.

Botanical name	Common name	AS 5604 In ground durability	AS 5604 Above ground	Heartwood colour
E. bosistoana	Coastal grey box	1	1	light brown/pink
E. cladocalyx	Sugar gum	1	1	yellow brown
E.quadrangulata	White topped box	1-2	1-2	pale yellow brown
E. eugenioides	Thinned leaved stringy bark	3	2	light brown
E. globoidea	White stringy bark	2	-	dark brown/pink
E. macrorhyncha	Red stringy bark	3	1	pink/brown
E. argophloia *	Qld western white gum	1	1	dark red/brown
E. longifolia	Woollybutt	1	1	red
E. tricarpa	Red ironbark	1	1	dark red
E. camaldulensis	Red river gum	2	1	red
E. notabilis	Blue mountains mahogany	-	-	dark red

Note * durability classification reported in State of Queensland, Department of Agriculture, Fisheries and Forestry, *E. argophloia* fact sheet 2013.

Seed/genetic sources included in demonstration trials

The genetic origin of seedlots planted in NZDFI's demonstration trials range from provenance and individual tree collections in natural Australian forest stands and collections from New Zealand first-generation seedling stands. They include the first clonal plants from cuttings of *E. bosistoana*.

See Appendix 1 for details of the species' genetic source and the year that they were planted in demonstration trials.

Site selection for demonstration trials

The objective of NZDFI's demonstration trials is to assess individual species' performance across varying environmental conditions and compare the long-term adaptability, form and productivity of each species.

NZDFI attracted significant interest from diverse of landowners who offered a range of trial sites in different environments. Many of these landowners provided significant in-kind support with trial layout, site preparation, planting and seedling/clonal nursery stock costs. By establishing demonstration blocks, these landowners are gaining knowledge and confidence in selecting species and developing the skills to establish new eucalypt plantations.

The natural range of the selected species in Australia was taken into account to broadly match regions in New Zealand that offer similar climatic conditions. Almost all of the species are endemic to the eucalypt forests and woodlands of the south-eastern states of Victoria and New South Wales. Exceptions are (i) *E. cladocalyx*, which occurs naturally in South Australia, (ii) *E. camaldulensis,* which is ubiquitous across the inland drier zones of the entire continent and (iii) *E. argophloia* which is endemic to a small region of Queensland. Despite Tasmania having similar environmental conditions to some New Zealand regions, no Tasmanian species were selected for testing as none of its 29 species produce class 1 or 2 durable heartwood.

New Zealand has many diverse regional environments as the two main islands extend 1,600 kilometres from 35 degrees latitude in the north to over 46 degrees south with a variable climate and underlying geology. Eastern regions are generally significantly drier than western regions. Northern regions are warm and often wet while the high mountainous interior of the South Island is dry and cold.

The lower altitude and warmer eastern regions of the North Island and the northern South Island were initially the focus for siting trials but sites extended to include other North Island regions both with higher rainfall and varying geology.

NZDFI planted a total of 33 demonstration trials at 30 different sites from 2010 to 2018 (Figure 1). The sites selected were generally farmland or forestry pine cutover sites. Sloping land and homogeneous aspects were preferred, flat sites can have a higher risk of frost and the tolerance amongst the species tested is variable.

Trial design and establishment

Between 2010 and 2018 approximately 659 individual species trial blocks were planted with a total of 47,591 seedlings. Most of the trials include 2-3 replicate blocks of each species. Each trial area was 1.5 - 3.0 hectares depending on the number of trees per block, block spacing, and number of species tested.

Sufficient area was required to mark out the blocks across even terrain, avoiding where possible areas with poor drainage or deep erosion scars. The layout of the trial blocks was adapted to the site area available. At some sites all trial blocks were laid out contiguously while at others some blocks are divided across discrete and variable microsites.

Blocks are demarked with a painted and numbered wooden peg at each corner and geo-mapped. Plant stocks were raised in containers at Morgans Rd Nursery located in Blenheim. This nursery had the skills and systems for successful propagation of all eucalypt species planted in the demonstration trials.

The first series of demonstration trials were planted in 2010, 2011 and 2012 at fourteen sites in the Bay of Plenty, Gisborne, Hawkes Bay, Wairarapa, Marlborough and Canterbury regions. Their establishment was funded by NZDFI supporters, landowners and the Ministry of Primary Industries (MPI) Sustainable Farming Fund (SFF) project 10-034. In this series, the block design is 49 trees

per block testing up to 11 species in a square spacing of 2.8 m between trees and between rows. Each species was generally replicated in two or three trial blocks across each site.

Most of these trials established well but there were exceptions. Three trials had low survival and/or poor growth due to either frost damage and/or poor soil drainage, sometimes compounded by severe weed competition. Another trial was heavily browsed by goats/deer leaving no measurable trees. These trials were subsequently abandoned. Table 2 shows the mean survival percentage at the sites planted in 2011 at an average age of 18 months. There have been further plot losses since then but updated survivals are not included for the analysis.

Table 2: Mean survival percentage at sites planted in 2011 (average tree age of 18 months).

Site	E. argophloia	E. bosistoana	E. camaldulensis	E. cladocalyx	E. eugenioides	E. globoidea	E. longifolia	E. macrorhyncha	E. notabilis	E. quadrangulata	E. tricarpa
Alex	77.6	88.3	98.0	51.0	78.1	65.8	85.0	84.2	83.7	98.6	
Craigmore	48.0	86.4			64.8	56.5	71.4	75.5	86.7	82.3	
Dillon	87.8	94.6	98.6	87.1	86.4	83.7	85.0	95.2	75.5	85.0	96.6
Marl Lines		78.6				83.7				90.8	
Martin	78.2	86.4	99.2	37.4	70.7	51.7	95.2	6.8	82.7	97.3	81.2
McNeill	87.8	94.6	99.3	92.5	94.6	92.5	96.6	87.8		99.0	95.9
Ngaumu		78.2	93.2			72.1	82.3	63.9	76.5	79.6	83.7
Saggers	96.9	95.9	98.6	79.6	86.4	82.3	90.5	89.8	91.8	95.2	96.6
Tect	59.2	78.2	85.0	16.3	63.3	53.1	82.3	66.7		86.4	83.0
Trimble	90.8	89.1	96.6	62.6	44.9	42.9	80.3	68.7	61.2	90.5	93.9
Wishart	73.5	87.8	93.9	79.6		85.7	83.0	81.0	87.8	92.5	85.7

In 2013 and 2014 a further series of eleven demonstration trials with a reduced list of species were planted under a second NZDFI SFF project (13-024). This project enabled NZDFI to support ten new landowners to plant durable eucalypt trials and extended the site types under test. Trials were established in Hawkes Bay, Wairarapa, Manawatu, Rangitikei, Tasman and Canterbury regions.

The number of species planted in the 2013 trials was reduced to six, however this was increased to eight in most of the trials planted in 2014.

The trial block size was increased from 49 trees to 100 trees to retain sufficient trees to measure stand productivity over a full rotation of up to 30 years. While the same square spacing of 2.8m x 2.8m was retained at some sites, others were planted at a higher stocking, 2.3m x 2.3m to measure the development and growth of trees under a short rotation post/pole regime of 15 to 20 years.

Establishment of these trials was successful with only partial loss of some blocks in two trials due to frost. Another trial was browsed by goats and deer but sufficient measurable trees are remaining.

In 2015, NZDFI became a partner in the Specialty Wood Products Research Partnership (SWP), a seven-year Ministry for Business Innovation and Employment (MBIE)/industry partnership. This enabled the establishment of new demonstration trials at eight sites in 2018. A reduced list of six species and seedlots were deployed for these trials. The first improved germplasm of *E. globoidea* was available and was planted alongside unimproved seed sources of these species to evaluate the genetic gain. These trials were established in Northland, Waikato, Bay of Plenty, Taranaki, Hawkes Bay, Horizons and Marlborough with two at the same locality of earlier sites

Appendix 2 provides a record of all trial sites established by NZDFI 2010-2018. All sites are mapped to show the species/block layout and PSPs.

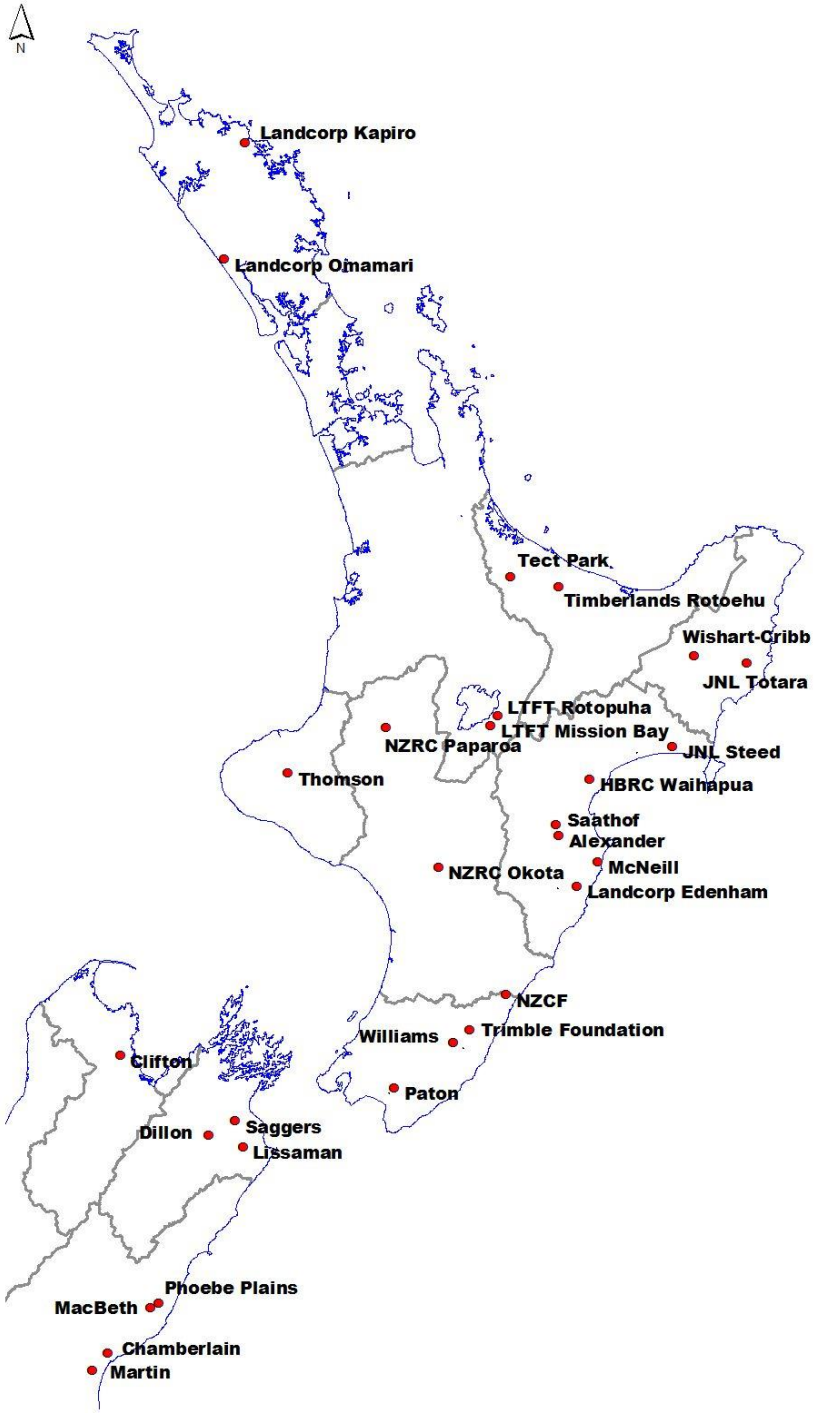


Fig 1: NZDFI demonstration trial sites planted 2010 - 2018.

Permanent Sample Plot measurement programme

The repeated measurement of permanent sample plots (PSPs) over the long term is necessary to capture and understand the 'site x species' differences that influence species' performance. Data collected from the PSPs across the diversity of NZDFI's trial sites is analysed to evaluate the performance and phenotypic variability and develop site adaptability and productivity models for each species.

Based on these data, a decision support system can be created to optimize initial stocking and stand management for short rotation post/pole regimes, medium rotation sawlog regimes and long-term permanent carbon forests.

Most sites have two to three replicate blocks per species. Following establishment, a minimum of two blocks of each species were selected within each trial and measured as PSPs. Growth and survival between blocks of the same species can vary due to microsite influences. For example, the minimum and maximum survival percentage of blocks planted at Alexander is shown in Fig. 2. There is 75% difference in survival between the three blocks planted with *E. cladocalyx.*

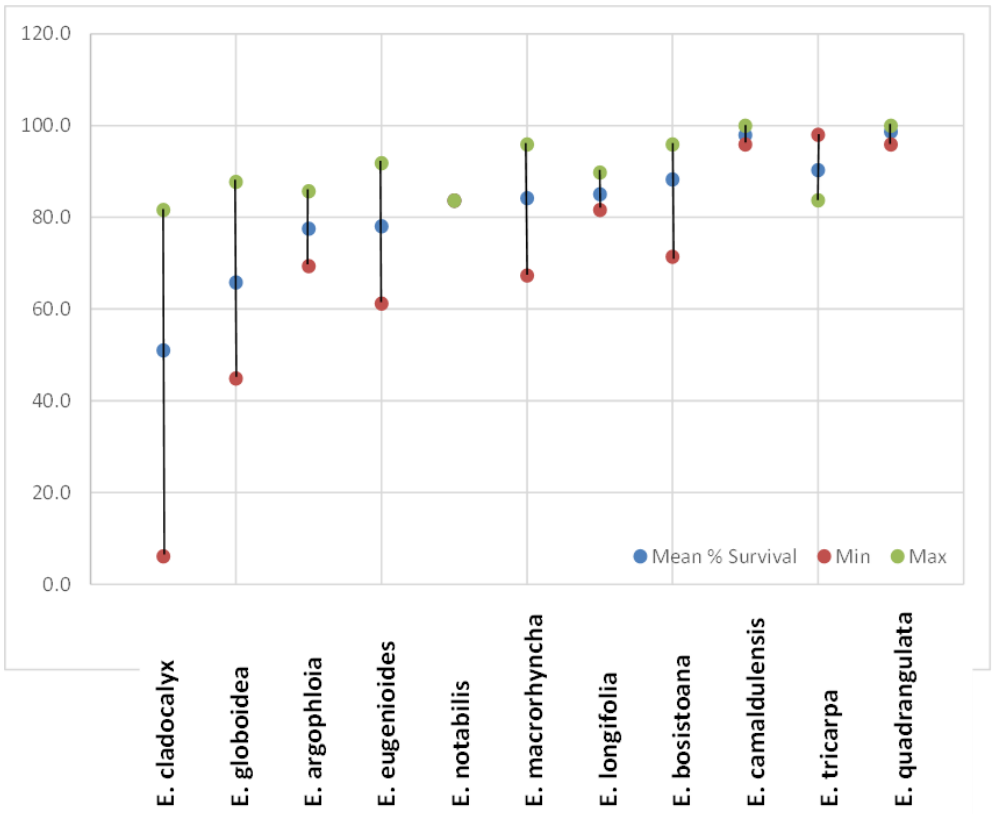


Fig 2: Minimum and maximum survival percentages of species planted in different blocks at Alexander.

Initial selection of a block for PSP measurement was generally determined by (i) survival of at least 60% of the original trees planted and (ii) a minimum of 80% of the surviving stems are of sufficient height for the measurement of stem diameter at breast height (DBH being 1.4 m).
NZDFI has established 560 PSPs across the network of demonstration trials.

The first PSPs were established by University of Canterbury (UC) School of Forestry students during the 2013/14 summer in some of the faster growing trials established in 2010 and 2011. This continued in subsequent years extending to the 2013 and 2014 trials.

The first analysis of PSP data measured in the 2010-2014 trials was reported in 2016 as part of the Ministry of Primary Industries (MPI) Sustainable Farming Fund (SFF) project 13-034. The annual PSP student measurement programme continued in summer of 2017/18.

From August 2020 to May 2022 the PSP measurement programme was funded both by SWP and NZDFI. PSPs located in some of the older demonstration trials were re-measured, as well as new PSPs established across eight of the 2018 demonstration trials. In total, 371 PSPs were remeasured in this period across 21 sites. At three of these sites there are PSPs located in trials that were planted in different years in adjacent locations.

ANALYSIS OF DATA

Variable age at time of measurement and selection of data for analysis

NZDFI's demonstration trials were planted over a period of six years and are located across a diversity of environments and regions to measure the comparative productivity across different sites.

Some species are capable of very rapid early growth rates while others are a little slower to start and then accelerate after two to three years. Calculating the mean annual growth rate of eucalypts based on trees measured at age three is significantly different to trees aged 7 or more. Therefore, to retain some consistency in the comparison of the data, only PSPs remeasured between 2020 and 2022 in the 2011, 2013 and 2014 trials have been used in the analysis. This is a total of 242 PSP data sets from a total of 14 trial sites.

All blocks in the JNL Steed site planted in 2012 had poor survival and this site was excluded entirely.

The dispersed locations, large number of plots and limited resources resulted in different measurement ages across this group of PSPs. Therefore, any analysis needed to take into account the 'age at measurement'. The range in the ages at last measurement is 7 to 11 years.

Species x sites PSP measurement data

The number of species planted each year and at each site is variable. The demonstration trials established in 2011 included eleven species. Early results from these trials indicated that *E. argophloia, E. notabilis* and *E. eugenioides* were less robust and vigorous than others, so these species were excluded from later trials.

The 2013 and 2014 trials include only 6 and 8 species respectively.

At most sites there were 3 replicate trial blocks included of each species, sometimes only 2, occasionally 4 with only one trial, MacBeth, planted with 1 replicate block per species.

If possible, all replicate blocks were remeasured in the 2020-2022 programme. However, this wasn't feasible at several sites due to a lack of resources with a priority given to measuring those species in the NZDFI's breeding programme.

Therefore, the data sets are unbalanced between species in the number of sites represented and the number of PSPs per site. This ranges from *E. globoidea* represented at all 14 sites with a total of 38 PSPs while *E. notabilis* is represented at only 5 sites with a total of 9 PSPs. Fig. 3 displays the distribution of plots by species across all sites.

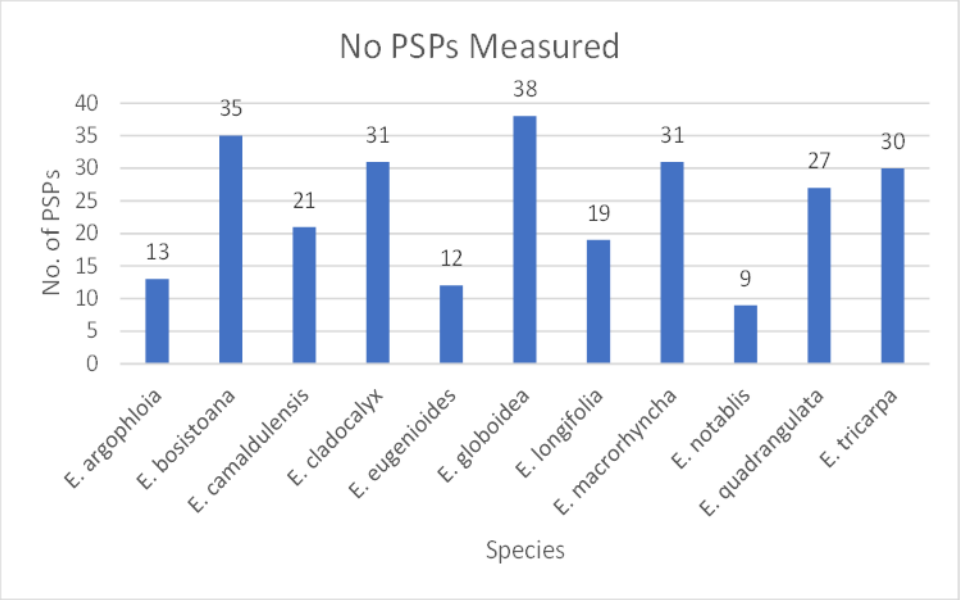


Fig 3:. Number of PSPs measured by species across all sites.

At some sites there is variation in growth between the PSPs of the same species that may be due to microsite influences like aspect, slope, drainage and exposure. In this analysis, for all sites where multiple PSPs of a species were measured, the data has been combined to calculate an average mean top height mean annual increment (MTHMAI) i.e. the average height increase per year for each species.

Overall average species productivity analysis

An overall productivity analysis of each species has been undertaken using ANOVA and R.Mean top height mean annual increment (MTHMAI) of the tallest 25% of trees of each species represented in the 2011, 2013 and 2014 trial sites have been calculated based on tree age at the time of measurement.

Species diameter at breast height x height analysis

The natural stem form or shape can vary between species. It is known that some species as they age become inherently shorter relative to the stem diameter and have significant taper while other species are tall and have minimal taper. Depending on the age of harvest, this influences the log dimensions produced and the value of the tree.

One of NZDFI's goals is the production of class 1 durable roundwood for agricultural posts and poles. A tree that produces a long straight stem with minimal taper and a high percentage of heartwood would be most suitable for this use.

Within a stand the DBH and height relationship is also influenced by: (i) how closely spaced the trees are planted (ii) initial losses and subsequent natural mortality; and (iii) any thinning to reduce competition and encourage diameter growth to ensure the stand reaches an optimal diameter range by harvest. In the case of a short rotation for post and poles this could be a range of between 250 - 350 mm diameter under bark to yield a peeled post diameter of between 80 – 200mm.

RESULTS

Overall species ranking for average growth and variance

The tallest 25% of trees of each species at all sites measured during 2020-2022 was used to calculate the mean top height annual increment (MTHMAI) i.e. the average height increase per year for each species.

The ANOVA result in Table 3 shows significant differences between species across all sites. *E. globoidea* with an average of 1.28 m is overall the best performer, however there is large variation within species because of differences between plots at the same site.

Table 3: Analysis of Variance (ANOVA) results ranking growth and variance between species.

Anova: All Sites x Species

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
argophloia	6	4.466673	0.744446	0.036942
bosistoana	14	13.71223	0.979445	0.100776
camaldulensis	13	12.11018	0.931553	0.116288
cladocalyx	13	13.57472	1.044209	0.183614
eugenioides	6	5.489943	0.914991	0.046625
globoidea	14	17.96917	1.283512	0.170687
longifolia	11	9.455236	0.859567	0.102015
macrorhyncha	14	15.24135	1.088668	0.137892
notabilis	5	3.593504	0.718701	0.050217
quadrangulata	12	12.89457	1.074548	0.10341
tricarpa	13	11.00197	0.846306	0.116368

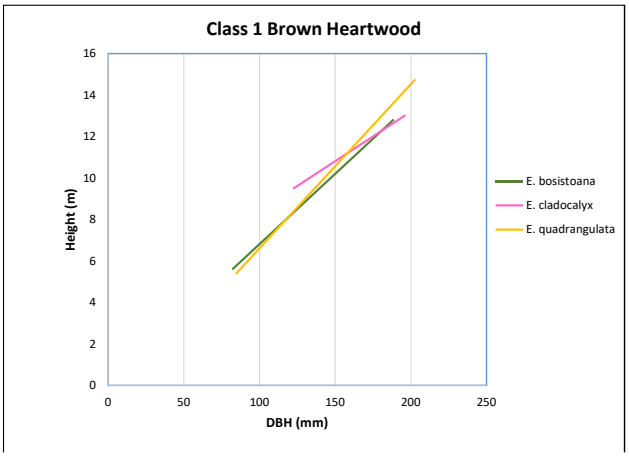
ANOVA

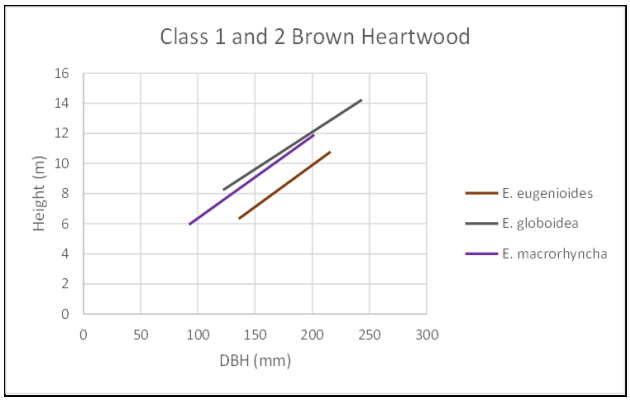
Source of Variatio	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.73081	10	0.273081	2.294236	0.017411	1.917827
Within Groups	13.09321	110	0.119029			
Total	15.82402	120				

Species diameter at breast height x height results

The relationship between diameter at breast height (DBH) and height has been determined for all 11 species. Most of the demonstration trials were planted at the same 2.8 m x 2.8 m spacing of and at the age of measurement had not been thinned. The data have been consolidated across all sites and the range of tree age to produce the results shown in Fig.4.

The slope of the regression lines for *E. longifolia, E. bosistoana* and *E. quadrangulata* show these species have a propensity to grow tall and thin trees compared to other species in the trials. This relationship in some species changes as they age and can result in a tree with a large diameter compared to the stem height. A dataset across a larger range of ages is required to accurately model this relationship.





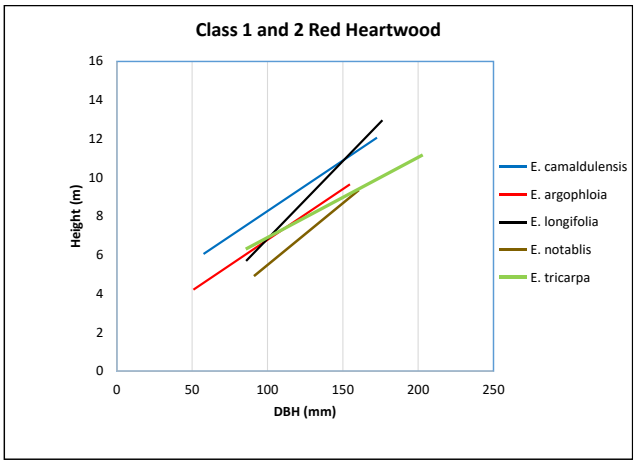


Fig 4: Examples of relationship between height and diameter for all species across all sites.

In the following section, results describing the comparative growth of different species are presented in species groupings according to their durability class and timber colour:

- Class 1 Brown Heartwood,
- Class 2 and 3 Brown Heartwood
- Class 1 and 2 Red Heartwood

Class 1 Brown Heartwood Species

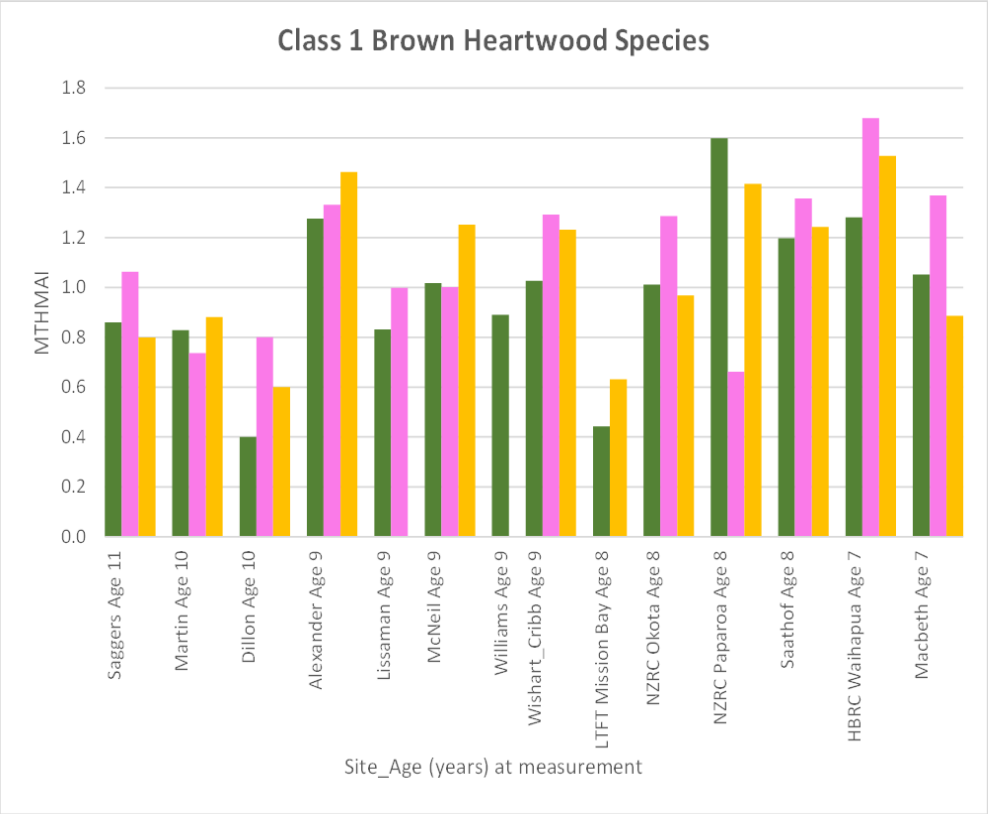


Fig 5: Class 1 brown heartwood species comparative growth Mean Top Height Mean Annual Increment (MTHMAI) across all sites.

Table 4: Class 1 brown heartwood species Mean Top Height Mean Annual Increment (MTHMAI) across sites and species.

Site / Landowner	Region	Age at Measurement (Years)	E. bosistoana Coastal grey box	E. cladocalyx Sugar gum	E. quadrangulata White topped box
			Class 1 Brown Heartwood		
LTFT Mission Bay	Waikato	8	0.4		0.6
NZRC Okota	Horizons	9	1.0	1.3	1.0
NZRC Paparoa	Horizons	8	1.6	0.7	1.4
Wishart	Gisborne	9	1.0	1.3	1.2
Alexander	Hawkes Bay	9	1.3	1.3	1.5
HBRC Waihapua	Hawkes Bay	7	1.3	1.7	1.5
McNeil	Hawkes Bay	9	1.0	1.0	1.3
Saathof	Hawkes Bay	8	1.2	1.4	1.2
Williams	Wairarapa	9	0.9		
Dillon	Marlborough	10	0.4	0.8	0.6
Lissaman	Marlborough	9	0.8	1.0	
Saggers	Marlborough	11	0.8	0.9	1.1
Macbeth	Canterbury	7	1.1	1.4	0.9
Martin	Canterbury	10	0.8	0.7	0.9
Mean across all sites			1.0	1.1	1.1

E. bosistoana - Coast grey box

E. bosistoana is represented by PSPs measured in every demonstration trial assessed in the 2020-22 programme. Therefore, the results for this species are based on data analysis from 35 PSPs located across the 14 trial sites. There is no other species that has been so successfully established in all of the 2010-2014 demonstration trials.

While the overall MTHMAI across these 14 sites is 1m, there is a high degree of variability with the highest productivity measured in the trial located in the NZ Redwood Company (NZRC) Paparoa forest near Taumaranui. Here the MTHMAI is 1.6m which is 0.3m more than the next three most productive sites that are all in Hawkes Bay and include Hawkes Bay Regional Council (HBRC) Waihapua forest, Saathof and Alexander. There are four trials with average productivity (1m MTHMAI): McNeil; Wishart/Cribb; NZRCs Okota Forest and MacBeth.

The four sites with low productivity (0.8-0.9m) are Saggers, Martin, Lissaman and Williams with two very low productivity (0.4m) being Dillon and Lake Taupo Forest Trust trials. There is a 400% difference in productivity between the best and worst sites.

A breeding population of *E. bosistoana* was established by NZDFI in 2009, 2010 and 2012 with 191 open-pollinated family seedlots collected from native forest stands in Australia. A sub-set of 50 of the family seedlots from the 2009 and 2010 trials were combined into a mixed seedlot and was deployed in the 2011 demonstration trials.

Some families planted in the 2010 progeny trial (of which 14 were included in the 2011 demonstration trial) displayed very different morphology and slower growth compared to those planted in 2009. These same morphological differences were observed among 15 – 20% of the seedlings planted in 2011 demonstration trials.

A University of Canterbury PhD student has employed genetic markers and taxonomy to determine the genetic relatedness within NZDFI's breeding populations of *E. bosistoana*. The research concludes that the families displaying different morphology and slow growth are *E. melliodora* (Yellow box).

Therefore, the 2011 demonstration trials have a mix of these two species and the analysis includes data collected from *E. melliodora* trees that negatively biases the results.

In 2013 and 2014 an Australian native forest provenance seedlot from Cann River stand seedlot was deployed in the demonstration trials.

E. cladocalyx - Sugar gum

Data has been analysed for the 31 PSPs located across the 12 trials assessed in the 2020-2022 measurement programme. It was not planted at Williams and failed at LTFT.

The overall average MTHMAI is 1.1m but there is a high degree of variability demonstrated in the results that is similar to that presented by *E. bosistoana.*

The highest productivity was measured in the trial located in HBRC Waihapua. Here the MTHMAI is 1.7m which is 0.3m more than the Saathof and MacBeth trials that are the next two most productive. These are closely followed by Alexander, Wishart/Cribb and NZRC Okota at 1.3m with McNeil and Lissaman that are below average productivity at 1m.

The sites with low productivity (0.8-0.9m) are Saggers, Martin, Dillon and NZRC Paparoa. This is 100% lower in productivity compared to the highest (1.7m) at HBRC Waihapua.

The seedlot deployed at all sites was sourced from the Australian Low Rainfall Tree Improvement Group breeding programme. Trees selected in the 1st generation breeding programme for growth

and form were established in a clonal seed orchard in 2010 and a mixed family improved seedlot is produced in this orchard.

E. quadrangulata - White topped box

E. quadrangulata is represented at every site in the demonstration trial series planted in 2011 and 2014 but was not included in the 2013 trial series due to unavailability of seedlings. These results are based on data analysis from 27 *E. quadrangulata* PSPs located across 12 trials assessed during the 2020-2022 measurement programme.

This species has also proven to be widely adaptable across diverse site conditions but as with the other two species, the difference in growth and survival between the best and worst site is significant.

The two highest productivity trials measured with 1.5m MTHMAI are at HBRC Waihapua and Alexander, with NZRC's Paparoa trial growing at 1.4m. Above average productivity (1.1-1.3m) occurred at Saathof, McNeil, Saggers and Wishart/Cribb.

The NZRC Okota trial has average productivity (1m) with lower productivity (0.9m) measured in the trials at Martin and MacBeth with two very low productivity (0.6m) trials being Dillon and Lake Taupo Forest Trust trial near Mission Bay. This is around 150% lower in productivity compared to the highest (1.5m) at HBRC Waihapua and Alexander sites.

E. quadrangulata was also selected by NZDFI for a breeding programme and in 2011 20 seedlots sourced from the Australian Tree Seed Centre were established in progeny trials with a further 89 families collected in native forest stands in Australia planted in 2016.An unimproved single provenance seedlot from Mt Skanzi was deployed in the 2011 and 2014 demonstration trials.

Class 2 and 3 Brown Heartwood Species

Fig 6: Class 2 and 3 brown heartwood species comparative growth Mean Top Height Mean Annual Increment (MTHMAI) across all sites.

Table 5: Class 2 and 3 brown heartwood species Mean Top Height Mean Annual Increment (MTHMAI) across sites and species.

Site / Landowner	Region	Age at Measurement (Years)	E. eugenioides	E. globoidea	E. macrorhyncha
			Thinned leaved stringy bark	White stringy bark	Red stringy bark
			Class 2 and 3 Brown Heartwood		
LTFT Mission Bay	Waikato	8		1.5	1.4
NZRC Okota	Horizons	9		1.3	1.3
NZRC Paparoa	Horizons	8		1.8	1.7
Wishart	Gisborne	9	1.1	1.4	1.2
Alexander	Hawkes Bay	9	1.1	1.5	1.3
HBRC Waihapua	Hawkes Bay	7		1.9	1.6
McNeil	Hawkes Bay	9	1.0	1.1	1.1
Saathof	Hawkes Bay	8		1.9	1.2
Williams	Wairarapa	9		1.1	0.9
Dillon	Marlborough	10	0.6	0.8	0.7
Lissaman	Marlborough	9		0.8	0.9
Saggers	Marlborough	11	1.1	1.0	0.9
Macbeth	Canterbury	7		1.3	0.9
Martin	Canterbury	10	0.7	0.7	0.3
Mean across all sites			0.9	1.3	1.1

E. eugenioides - Thinned leaved stringy bark

E. eugenioides was only included in the demonstration trial series planted in 2011. These results are based on data analysis from 12 PSPs located across 6 trials assessed in the 2020-2022 measurement programme. Across these six sites there is considerable variability with an overall average of 0.9m.

The most productive trials are located at Alexander, Wishart/Cribb and Saggers all with 1.1m MTHMAI recorded.

The McNeill site was slightly lower 1.0m with 0.7m at Dillon and the lowest productivity of 0.6 m at Martin.

An unimproved seedlot obtained from the Australian Tree Seed Centre was deployed.

E. globoidea - White stringy bark

E. globoidea was planted in every demonstration trial from 2011-2014. These results are based on data analysis from 38 PSPs located across 14 trials that were assessed in the 2020-2022 measurement programme. Survival at Martins was poor due to frost and poor drainage, however measurements from this site have been reported.

This species has recorded the highest MTHMAI of any species and also has the highest overall average of 1.3m. However, as with the class 1 brown heartwood species already presented there is a high degree of variability demonstrated by the results with this variability being particularly significant for *E. globoidea*.

Table 6 shows the results of a Tukey-Kramer analysis. The Q-crit value = 4.1 for the difference in means between species to be statistically significant. The highlighted cells show that *E. globoidea* MTHMAI is significantly different to *E. argophloia, E. longifolia, E. notablis* and *E. tricarpa* across all sites at P=0.01.

Table 6: Comparison of the variability of E. globoidea with that of other species.

	argophloia	bosistoana	camaldulensis	cladocalyx	eugenioides	globoidea	longifolia	macrorhyncha	notabilis	quadrangulata	tricarpa
argophloia		1.9741	1.5540	2.4896	1.2108	4.5285	0.9298	2.8917	0.1743	2.7062	0.8460
bosistoana	1.9741		0.5097	0.6892	0.5415	3.2977	1.2196	1.1845	2.0515	0.9909	1.4169
camaldulensis	1.5540	0.5097		1.1773	0.1376	3.7457	0.7203	1.6721	1.6580	1.4642	0.8909
cladocalyx	2.4896	0.6892	1.1773		1.0732	2.5468	1.8475	0.4731	2.5355	0.3107	2.0682
eugenioides	1.2108	0.5415	0.1376	1.0732		3.0958	0.4476	1.4590	1.3288	1.3081	0.5705
globoidea	4.5285	3.2977	3.7457	2.5468	3.0958		4.3131	2.1131	4.4439	2.1774	4.6530
longifolia	0.9298	1.2196	0.7203	1.8475	0.4476	4.3131		2.3308	1.0706	2.1111	0.1327
macrorhyncha	2.8917	1.1845	1.6721	0.4731	1.4590	2.1131	2.3308		2.9109	0.1471	2.5793
notabilis	0.1743	2.0515	1.6580	2.5355	1.3288	4.4439	1.0706	2.9109		2.7403	0.9940
quadrangulata	2.7062	0.9909	1.4642	0.3107	1.3081	2.1774	2.1111	0.1471	2.7403		2.3371
tricarpa	0.8460	1.4169	0.8909	2.0682	0.5705	4.6530	0.1327	2.5793	0.9940	2.3371	

The most productive sites measured are HBRC Waihapua and Saathof. In both trials the MTHMAI is 1.9m with the NZRC Paparoa trial growing at 1.8m which is 0.3m more than LTFT Mission Bay and Alexander trials at 1.5m.

MTHMAI at Wishart/Cribb is 1.4m with both NZRC Okota and MacBeth MTHMAI at average productivity (1.3m). Williams, McNeill and Saggers all have lower productivity (1.1m) and three sites with low productivity (0.8-0.9m) that are Martin, Dillon and Lissaman. These sites are over 200% lower in productivity compared to the highest (1.9m) at HBRC Waihapua.

An unimproved provenance seedlot from Cann River was deployed in all these trials with the addition of two other unimproved Australian seedlots, one added in 2011 and another in 2014 demonstration trials.

NZDFI established a breeding population of *E. globoidea* in three progeny trials planted in 2011 with seedlings of 160 individual family seedlots.

E. macrorhyncha - Red stringy bark

E. macrorhycnha is also represented in every demonstration trial planted from 2011-2014. Like *E. globoidea,* survival at Martins was poor due to frost and poor drainage, however measurements from this site have been reported. These results are based on data analysis from 31 PSPs located across 14 trials.

Consistent with other species there is a high degree of variability in the results. The overall pattern of this variability is similar to that of *E. globoidea* with a large difference between the minimum and maximum MTHMAI.

The most productive sites are located in the NZRC Paparoa trial with MTHMAI at 1.7m and 1.6m in HBRC Waihapua. The LTFT Mission Bay trial is growing at 1.4m with Alexander and NZRC Okota both at 1.3m.

With MTHMAI's of 1.2m both Wishart/Cribb and Saathof are above the average of 1.1m that is recorded at McNeill. MacBeth, Lissaman, Saggers and Williams all share a MTHMAI of 0.9m with Dillon at 0.7 m and the lowest productivity of 0.3m at Martin. This is around 500% lower in productivity compared to the highest (1.7m) at the NZRC Paparoa site.

A mix of three unimproved Australian provenance seedlots were deployed in 2011 and then again in 2014. In 2013, a collection was made from elite trees within a small NZDFI seedling seed stand and seedlings grown from this seed were deployed in these trials.

Class 1 - 2 Red Heartwood Species

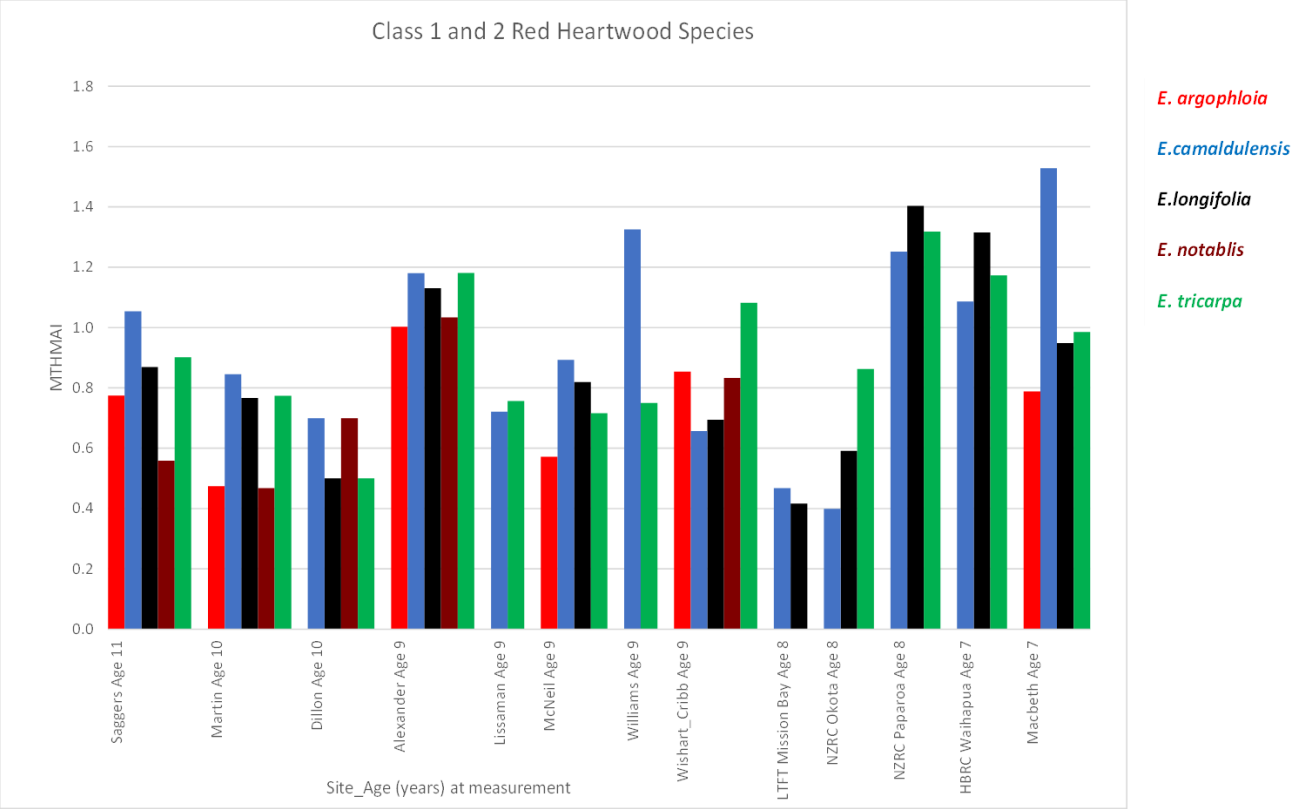


Fig 7: Class 1 and 2 red heartwood species comparative growth Mean Top Height Mean Annual Increment (MTHMAI) across all sites.

Table 7: Class 1 and 2 red heartwood species Mean Top Height Mean Annual Increment (MTHMAI) across sites and species.

Site / Landowner	Region	Age at Measurement (Years)	E. argophloia Qld western white gum	E. camaldulensis Red river gum	E. longifolia Woollybutt	E. notabilis Blue mountains mahogany	E. tricarpa Red ironbark
			Class 1 and 2 Red Heartwood				
LTFT Mission Bay	Waikato	8		0.5	0.4		
NZRC Okota	Horizons	9		0.4	0.6		0.9
NZRC Paparoa	Horizons	8		1.3	1.4		1.3
Wishart	Gisborne	9	0.9	0.7	0.7	0.8	1.1
Alexander	Hawkes Bay	9	1.0	1.2	1.1	1.0	1.2
HBRC Waihapua	Hawkes Bay	7		1.1	1.3		1.2
McNeil	Hawkes Bay	9	0.6	0.9	0.8		0.7
Saathof	Hawkes Bay	8					
Williams	Wairarapa	9		1.3			0.8
Dillon	Marlborough	10		0.7	0.5	0.7	0.5
Lissaman	Marlborough	9		0.7			0.8
Saggers	Marlborough	11	0.9	0.9	0.6	0.8	0.9
Macbeth	Canterbury	7	0.8	1.5	0.9		1.0
Martin	Canterbury	10	0.5	0.8	0.8	0.5	0.8
Mean across all sites			0.8	0.9	0.8	0.8	0.9

E. argophloia - Queensland western white gum

E. argopholia was only included in the demonstration trial series planted in 2010 and 2011. These results are based on data from 13 PSPs located across 6 trials assessed in the 2020-2022 measurement programme.

Once again even across these fewer sites there is variability with an overall average MTHMAI of 0.8m. The most productive trial is located at Alexander with MTHMAI recorded of 1.0m. Both Wishart/Cribb and Saggers recorded 0.9m and MacBeth 0.8m.

The McNeill trial recorded 0.6 m and the lowest productivity of 0.5m at Martin. This is around 100% lower in productivity compared to the highest (1.1m) at the Alexander site.

The seedlot deployed throughout all of these trials originated from a seedling seed orchard established in the 1990s by the Department of Primary Industries, Queensland, tree conservation programme.

E. camaldulensis – Red river gum

E. camaldulensis was included in every site in the demonstration trial series planted in 2011 and in all sites planted in 2013 and 2014 except Saathof. Therefore, these results are based on data analysis from 21 PSPs located across 13 trials assessed in 2020-2022 measurement programme.

There is a high degree of variability across sites in the results.

It is most productive in the Macbeth trial with MTHMAI at 1.5m and 1.3m in NZRC Paparoa and Williams. The Alexander trial recorded 1.2 m and HBRC Waihapua 1.1m.

MTHMAI's of 0.9 m were recorded at both McNeil and Saggers with Martin at 0.8m and Wishart/ Cribb, Dillon and Lissaman all at 0.7m. The lowest productivity of 0.4 m was at NZRC Okota.

The seedlot planted at all the trials originated from a seedling seed orchard in Western Australia that was producing seed of *E. camaldulensis* for soil conservation planting.

E. longifolia - Woollybutt

E. longifolia was included in 11 demonstration trial series planted in 2011 and 2014. These results are based on data analysis from 19 PSPs.

It is most productive in the NZRC Paparoa trial with MTHMAI at 1.4 m and 1.3 m in HBRC Waihapua. The Alexander trial is 1.1m, MacBeth is 0.9m.

MTHMAI's of 0.8m were recorded at both McNeil and Martin with Wishart-Cribb on 0.7m and Saggers and NZRC Okota both a MTHMAI of 0.6m with Dillon at 0.5m and the lowest productivity of 0.4m at LTFT Mission Bay.

A single Australian natural forest unimproved seedlot was deployed in 2011 and then again in 2014.

E. notabilis – Blue mountains mahogany

E. notabilis was only included in the demonstration trial series planted in 2011 and 9 PSPs located across 5 trials were measured.

The species has performed poorly at all locations. Alexander recorded a MTHMAI of 1.0m. Both Wishart/Cribb and Saggers recorded 0.8m. The Dillon trial recorded 0.7m and the lowest productivity of 0.5m is at Martin.

An unimproved Australian provenance seedlot was purchased by Proseed and deployed in 2011.

E. tricarpa – Iron bark

E. tricarpa was planted at 13 sites, however the LTFT Mission Bay site had low initial survival and very poor growth. Therefore, these results are based on data analysis from 30 PSPs located across 12 trials assessed in the 2020-2022 measurement programme.

As with other species there is a high degree of variability in the results. The overall pattern of this variability is similar to that of *E. longifolia* although *E. tricarpa* has generally higher productivity with a slightly higher average MTHMAI of 0.9m.

It is most productive in the NZRC Paparoa trial with MTHMAI at 1.3m and 1.2m in HBRC Waihapua and the Alexander trial. Wishart/Cribb trial recorded 1.1m and MacBeth is 1.0m.

MTHMAI's of 0.9m were recorded at both Saggers and NZRC Okota with Martin, Lissaman and Williams 0.8m. McNeil was 0.7m with the lowest productivity of 0.5m at Dillon. This is around 250% lower in productivity compared to the highest (1.7m) at HBRC Waihapua.

A mix of two unimproved Australian seedlots were deployed in 2011 with only one of these planted in 2013 and 2014.

DISCUSSION

In this section, we review each species for:

- Natural Australian distribution and timber properties
- Any recent Australian forestry research and international plantation use.
- New Zealand introduction and experience
- NZDFI research focus and role in the breeding programme
- Adaptability, productivity and site preferences
- Stem form and branching habit
- Insect tolerance
- Onset of early flowering and seed production

Growing NZDFI's eucalypt species to produce naturally durable hardwood is a significant forestry and future wood processing opportunity for New Zealand. Our vision is for a network of regional hardwood industries across the North Island and northern South Island by 2050. For this to happen wood supply catchments of durable eucalypt forests need to be planted over the next 30 years.

Choosing the right species to match the planting site or selecting a productive planting site for a durable eucalypt species is critical to success. NZDFI's selection of eleven species for the establishment of a demonstration trial series took into account Australian knowledge of their natural forests and experience in utilising the timber of each species, along with any Australian, New Zealand and international forestry research and development.

The purpose of NZDFI's demonstration trials is to assess individual species' performance across varying environmental conditions and to compare the long-term adaptability, form and productivity of each species. Measurement of permanent sample plots (PSPs) in the 2011-2014 demonstration trials have provided the data to evaluate the performance and phenotypic variability in survival and growth, between sites and species across this trial network.

The measured outcomes and knowledge derived from the assessment of these trials have been summarised for each species and clearly demonstrate there is significant variability in adaptability and productivity between species and between sites. Overall, the warm east coast and central North Island sites have moderate to high productivity for class 2 brown species particularly with greater growth where there is higher rainfall.

The same applies for the class 1 brown and red species with the exception of the inland cooler 600m site at Lake Taupo on pumice soils; the NZRC Okota site located on inland Manawatu hill country at 400m is also geographically exposed; and the Williams site on central Wairarapa hill country. All these species recorded average or low productivity compared to the warmer wetter regions of northern Hawkes Bay and Gisborne.

The South Island east coast sites are cooler in winter and have lower rainfall with low to moderate productivity for most species. The exception is the MacBeth site that recorded high productivity for *E. cladocalyx*. This is a north facing sheltered site with a mix of loess and siltstone derived soils that highlights the value of careful site x species matching for better than average productivity in these regions.

Results presented for each species clearly demonstrate there is significant opportunity to select adaptable species that can be very productive in some New Zealand regions. There are also species that have been less productive or have failed at some sites. Forest growers can use this information to optimally match species to sites when planning the establishment of eucalypts.

A major disadvantage with the demonstration trial series is that the level of genetic diversity that could be tested with the limited resources available is poor. The seedlots planted in the trials are not broadly representative of the total natural distribution of the species. NZDFI has established

advanced breeding populations with five species, *E. bosistoana, E. globoidea, E. quadrangulata, E. tricarpa* and *E. argopholia*. These progeny trials test at an individual family level and seed is sourced where possible from across the natural range in Australia. Under the SWP programme many of these trials have been intensively assessed for growth, form and intrinsic wood properties to identify elite families for commercial seed production and deployment.

There has been minimal pruning and thinning in these demonstration trials. This has allowed observation of the diversity of natural stem form and branching habit of each species. This includes the natural architecture of each species stem and crown as well as the structural changes that occur in the crown as the trees grow from a seedling to sapling to pole (semi-mature) to mature stand. The ability of a species to shed branches during the early stages of growth, i.e. self-prune, is of particular interest. As the crown height increases, the branches on the lower stem become moribund, finally die and eventually drop. The effectiveness of each species in shedding branches is not a part of this study. However, general observations are given about the persistence of branches by each species.

The ability to coppice was a trait included during the selection of species for these trials. In trial blocks where trees have been thinned coppice regrowth has developed from the tree stumps of all species. Coppice reduces the vulnerability of harvested sites to erosion as the stumps retain living roots; also, regrowth and site occupancy is often much faster than by replanting seedlings. A coppice regime has been employed for many species for short rotation post and pole, and biomass production. However, it can require management to a single leader to produce a productive stem and control of unwanted regrowth is required particularly when improved genetics are planned for planting following a harvest.

Since planting, insect pests have impacted on the growth of some species at most sites. Seasonal leaf browsing from tortoise beetle, leaf roller and gum emperor moth has been observed but no study had been made of tolerance of each species. In March 2016, an incursion of the paropsine beetle *Paropsisterna variicollis* (eucalyptus variegated beetle) was detected in the Hawkes Bay during routine Forest Biosecurity Surveillance. This rapidly spread and NZDFI undertook a survey in January 2017 of three Hawkes Bay NZDFI trial sites - Alexander, McNeill and HBRC Waihapua. Levels of defoliation by paropsines, and numbers of eggs, larvae and adults were recorded for all 11 durable eucalypt species. Adult *Pst. variicollis* were observed on all eucalypt species, and were present in larger numbers than *Paropsis charybdis* in two sites.

Results for each species surveyed in this study were reported with *E. bosistoana, E. quadrangulata, E. tricarpa, E. camaldulensis and E. argopholia* sustaining the greatest defoliation, *E. eugenioides* and *E. longifolia* had moderate defoliation and *E. globoidea, E. cladocalyx,* and *E. macrorhyncha* had the least (Lin et al.Hawkes 2017).

Another physiological characteristic critical to advancing tree breeding of any species is the age of sexual maturity; the onset of anthesis (flowering) and seed production. This is influenced by species, genetics and environments. Therefore, during assessments of both demonstration and progeny trials the floral development has been recorded. In some species, this can start with only a few individuals well in advance of others that start several years later or not at all. Understanding the flowering biology of the species in the breeding programmes and seed orchards is important to ensuring outcrossing is occurring across the populations.

Flowering eucalypts produce nectar and pollen suitable for honey bees while native birds also forage for nectar along with native insects. Some flower at times of year when nectar and pollen is in short supply. Australian information and NZDFI records are reported on the web page Eucalypts and Bees - NZ Dryland Forests Innovation (nzdfi.org.nz)

Class 1 Brown Heartwood Species

E. bosistoana – Coast grey box

Eucalyptus bosistoana received early recognition for its forestry potential in Australia (Baker 1905) due to its class 1 durability and light-coloured brown/pink heartwood suitable for a wide range of applications. *E*. *bosistoana* is described as the largest growing of the 'box group' of eucalypts (Boland et al. 2006) often reaching a tree height of 30-40m and a stem diameter up to 1.5m. The natural distribution includes the NSW Southern Tablelands, the coastal areas of eastern Victoria (Gippsland) and N.S.W. south of Sydney (Hall et al.Hawkes 1963) where there is moderate rainfall, temperate summers and cool winters with frosts. It is the only box species that can be found in pure stands but also occurs in mixtures with other species including *E. globoidea* and *E. longifolia*. It is generally found on valley flats and lower slopes where there are better soils showing a preference for loams over limestone.

There has been no significant research in Australia or international plantation use of *E. bosistoana* aside from some recent provenance testing by Heartwood Plantations in East Gippsland (J. Lewis, Heartwood Plantations, pers. com.).

The species was an early introduction to New Zealand and several small mature stands demonstrated its adaptability to North Island regions located in Northland, Waikato, Hawkes Bay and the Wairarapa along with Marlborough in the South Island. A few early farm foresters planted *E. bosistoana* including Neil Barr, founder of the NZ Farm Forestry Association. He planted many eucalypt species in Northland during the 1960-1990's and reported that *E. bosistoana* grew favourably and when milled the species cut and seasoned well (Barr 1996).

In 2003 the species was selected by Vineyard Timbers as a potential candidate to grow for vineyard post production. From 2003 to 2007 the company collaborated with local landowners, the Marlborough Regional Council and Proseed NZ to establish regional trials of 25 eucalypt species that included *E. bosistoana*. *E. bosistoana* posts sawn from a mature stand in the Waikato were installed in local vineyards by Vineyard Timbers. The success of these trials led to the establishment of NZDFI in 2008 (Millen et al.. 2018).

E. bosistoana is a principal species in the NZDFI breeding programme based on its capability to produce class 1 durable hardwood suitable for vineyard posts within ground use expected to exceed 25 years. Between 2009 and 2021 NZDFI established 11 progeny trials to test a total of 247 open-pollinated seedlots collected from across the native range of the species in Australia. The most recent trials planted in 2021 under a Te Uru Rākau One Billion Trees partnership project included 29 second generation selections and 15 clones.

Assessments across of the 2009-2012 trials showed that the genetic parameters of growth and form as well as durable heartwood are under genetic control and can be improved through selective breeding by screening with near infrared spectroscopy (Y. Li et al.. 2020). A broad-based selection of top families and elite trees were identified within the progeny trials for grafting and a clonal orchard was planted by Proseed. Since 2021 this orchard has produced genetically improved open-pollinated seed.

The survival percentage across species and sites (Table 2) shows *E. bosistoana* establishes well. The NZDFI demonstration trials confirm the species is capable of productive growth rates on a range of sites. Notably it has proved to have high productivity on Hawkes Bay sites with limestone derived soils and sites with higher rainfall. The species has attained moderate productivity on a variety of other sites including being able to survive and thrive in some wet sites with both light and heavy soils. It is not suited to drier exposed sites that reduce height growth and encourage poor form.

One of the progeny trials sites planted in 2009 and 2010 is located on the Marlborough District Council Cravens Road reserve that is a berm of the Wairau River and has survived many flood events without significant damage.

The trees are thriving in the alluvial silt/gravel with some elite trees exceeding 2m annual height increment. Given this adaptability one of the 2021 progeny trials was planted in a similar river berm site alongside the Tukituki River that has survived flooding in winter 2022 and then severe flooding this year during Cyclone Gabrielle.

Across all of these trials and even more so in NZDFI's progeny trials, this species has shown extremely variable stem form and branching habitat. In some demonstration trials early form pruning was undertaken to correct this.
Trees grown from the seed collected in the clonal seed orchard will have improved productivity and stem straightness, branching habit, heartwood content and durability.

By the summer following planting insect browse of *E. bosistoana* foliage by well-established eucalypt pests has often been observed. This includes leafroller and eucalypt tortoise beetle (*Paropsis charybdis).* In 2015 the eucalypt variegated beetle, (*Paropsisterna varicollis)* was found in Hawkes Bay and this rapidly dispersed into all of the NZDFI trials in that region. By summer of 2022 it had been recorded in NZDFI trials in the Wairarapa, Marlborough and near Cheviot in North Canterbury.

Two University of Canterbury PhD students have been studying how paropsine insects *Paropsis charybdis* and *Pst. cloelia* interact with plantation eucalypts in New Zealand. The work involved quantifying the resistance and/or tolerance of *Eucalyptus* species, families and genotypes to paropsine attack and researching the diversity of potential predators.

Flowering and seed production was first observed on only a few individuals at the MDC Cravens Road site at age 7 years but at no other NZDFI site. Initiation of flowering is highly variable among the families planted in the breeding populations and many families have no floral development. Proseed have successfully applied *Paclobutrazol*, a known growth inhibiter used to enhance flowering and seed production in the clonal seed orchard.

The SWP programme has supported NZDFI to collaborate with local processors to successfully develop and test *E. bosistoana* products and associated technologies, including posts, poles, veneer and LVL utilising logs of young trees from trees planted in the Marlborough 2003-2007 trials. An early growth model and stem taper function have been developed. (See Appendix One for relevant Technical Reports.)

E. cladocalyx – Sugar Gum

Eucalyptus cladocalyx produces highly durable yellowish-brown timber that is hard, strong and termite resistant and was highly regarded by early settlers of South Australia where it naturally occurred (Baker 1906). It's use for posts, poles and general construction led to early farm forestry plantings from 1880's throughout South Australia and to being widely planted in the drier western areas of Victoria. In South Australia there are disjunct populations in Flinders Ranges, Eyre Peninsula and Kangaroo Island. The annual rainfall varies in these areas from 250mm - 600mm with summer drought common and temperatures exceeding 40 degrees. There are only mild winters with occasional frosts (Hall et al. 1963). *E. cladocalyx* can grow up to 35m in height and 1-1.5m in diameter in the higher rainfall areas and can produce a tree with straight trunk to two thirds the tree height (Boland et al. 2006).

E. *cladocalyx* is generally found growing on upper slopes and ridges except in Kangaroo Island where it grows near creeks. It grows in a wide range of skeletal, often shallow soils, derived from quartzite as well as sedimentary and limestone in some areas (Hall et al. 1963).

E. cladocalyx is extensively planted on farms in western Victoria and parts of southern inland NSW for amenity, shelter and timber production. There are successful plantations of *E. cladocalyx* in Spain, Portugal and southern African countries in areas with 400–600 mm winter maximum rainfall.

The Australian Low Rainfall Tree Improvement Group (ALRTIG) breeding programme was established in 1999 to work on potential forestry species to grow on a 20-year rotation in dryland south-eastern Australian sheep-wheatbelt regions with 400-650 mm annual rainfall. They included *E. cladocalyx* and reported it produces dense strong wood at a young age and some families develop durable heartwood by age 8-10 years. Evaluation of breeding trials showed this is under genetic control and highlighted the possibility to improve heartwood development in *E. cladocalyx* by family selection (Bush 2011). 1st generation improved seed for growth and form has been produced from this breeding programme and is the seedlot deployed by NZDFI in the demonstration trials.

While there are only a few known mature stands in Hawkes Bay and Wairarapa, NZDFI identified *E. cladocalyx* as a class 1 durable hardwood species of interest based on the Australian research and the species adaptability to dry hot exposed environments similar to the driest northern New Zealand east coast regions.

E. cladocalyx has been successfully deployed in many demonstration trials as well as larger scale block planting at several sites. However, it has proven to be one of the most frost sensitive of the NZDFI species with losses in the winter following planting and at a few sites, there was almost total block failure. It is also intolerant of poorly drained heavy soils. Otherwise, where it has been successfully established, it has grown vigorously particularly on drier sites with limestone or sedimentary derived soils where it has produced the highest MTHAI. However, on higher rainfall sites with possibly higher humidity it has performed poorly.

At most demonstration trial sites there is little insect browse or diseased foliage evident. Although the trials were planted with a 1st generation seedlot there is still considerable variability in tree form. Young trees may develop double leaders that form pruning can correct. Otherwise the species self-prunes with the best trees developing straight clear stems with a moderately large, rounded crowns.

The species has developed early and abundant flowering on many individuals at most sites. This characteristic offers the opportunity to advance a specific breeding programme in New Zealand to improve wood properties and frost tolerance. There has been a recent Victoria State government funded R&D project led by Forestry Australia to re measure the ALRTIG and other *E. cladocalyx* trials and to promote farm forestry in Victoria (Lacy 2023). Productivity models have been developed for *E. cladocalyx*, and NZDFI's demonstration trial data sets could be used to test the model's application in New Zealand.

E. quadrangulata - White topped box

Eucalyptus quadrangulata also received early recognition for its forestry potential in Australia (Baker 1905) due to its very hard and durable pale-coloured yellow brown heartwood suitable for a wide range of applications. *E. quadrangulata* can grow to 45m tall with a diameter of up to 1.5m (Boland et al. 2006). It can be found in several naturally occurring disjunct provenances on the slopes and tablelands of New South Wales up to 900m in altitude where there is moderate uniform rainfall and where summers are moderate and winters cool with frosts. It is found growing in association with a wide range of other species and in open situations retains its lower branches, while in closed forests it attains a long clean stem. It generally prefers heavy soils of shale or volcanic origin.

While there are no known mature stands in NZ, in the 1990's two farm foresters had successfully tested its adaptability to North Island regions including Northland and Hawkes Bay. The Marlborough regional trials planted from 2003 to 2007 included this species. These trials encouraged the selection of *E. quadrangulata* as a secondary species for NZDFI's breeding

programme based on the capability to produce class 1-2 durable hardwood. However, there was no recent Australian research or international plantaion use or previous breeding of this species and, in particular, no knowledge about its adaptability to drought.

NZDFI have tested it's environmental plasticity by planting on sites with annual rainfall below 900 mm.

Assessments of *E. quadrangulata* in both progeny trials and demonstration trials following establishment recorded consistently high survival. There have been two breeding populations of *E. quadrangulata* established in 2011 and 2016. 20 families sourced from CSIRO seed centre were planted in 2011 and another 75 families collected across the species disjunct populations were established in 2016. Growth and form assessments of the 2011 progeny trials have been completed along with heartwood and stiffness assessments. The results from the growth and form assessment of the 2011 progeny trials at age 9 years were reported, (Sharma 2022); heartwood quality, density and tangential collapse was also measured and reported (Gildiyahi 2023).

Early selections of these elite families have been grafted and established in a 1st generation seed orchard at Proseed however they are still not flowering. Similarly, there is no floral development at any of the demonstration or progeny trial sites and this is a major constraint to advancing genetic improvement of the species.

As with *E. bosistoana,* in the summer following planting insect browse of *E. quadrangulata* foliage by well-established eucalypt pests has often been observed. It has also been browsed by *Paropsisterna varicollis* (Eucalypt variegated beetle) in the regions where the insect has spread from Hawkes Bay where the first incursion was reported. .

Despite repeated seasonal defoliation events, sometimes severely impacting much of the full crown, the results recorded in NZDFI demonstration trials show that the species is capable of recovering and making productive growth rates on a range of sites. The highest productivity is on Hawkes Bay sites with limestone derived soils and sites with higher rainfall while the species has attained moderate productivity on a variety of other sites except where there is poor drainage. It is not suited to drier exposed sites that reduce height growth and encourage poor form.

Otherwise, this species generally has straight stems with some single leader trees but often with double and multi leaders developing in the lower stem. At very close spacing (2 m x 2 m) it will shed some of the lower branches and early form pruning and clear wood pruning has been successfully undertaken in some trial blocks. The height x diameter relationship shows that the species produces a stem with good diameter growth and less tree height compared to *E. bosistoana*. It's early fast growth and density could make it suitable for very short rotation coppice biomass regimes on good quality sites.

The SWP programme has supported NZDFI to collaborate with local processors to successfully develop and test *E. quadrangulata* products and associated technologies, including posts, poles, veneer and LVL utilising logs of young trees from trees planted in the Marlborough 2003-2007 trials. (See Appendix 1 for relevant Technical Reports).

Class 2 and 3 Brown Heartwood Species

E. eugenioides – Thin leaved stringybark

Eucalyptus eugenioides is one of three stringybarks planted in the NZDFI trials. It is class 2-3 durable with straight grained light brown or pink heartwood used for general construction in the regions it is found i.e. from southern Queensland and throughout eastern New South Wales. On favourable sites it can reach heights up to 30m and a diameter of 0.7m diameter (Boland et al. 2006). It grows on coastal lowlands, inland hill country and tablelands where there is a warm humid to sub-humid climate without major extremes. It typically grows in soils of moderate fertility derived from shales and slate (Boland et al. 2006).

There is no recent Australian research or international plantation use known of this species.

Neil Barr, founder of the NZ Farm Forestry Association planted *E. eugenioides* in Northland during the 1960-1990s. He was encouraged by the early production of durable timber and good milling properties.

The inclusion of *E. eugenioides* in NZDFI's demonstration trials was based on its potential adaptability to North Island east coast environments.

E. eugenioides was deployed in NZDFI's 2011 demonstration trials and early survival and performance was similar to that of the other two stringybarks in the trials. NZDFI did not include it in any later trials, however assessments in some PSPs were continued. Based on the data from the six trials that were measured, it has demonstrated its adaptability to northern New Zealand east coast regions. The seedlot tested is producing trees with a mix of single, double and occasionally multi leaders with reasonable straight stems, moderate branches and a medium density crown. Some individuals first started flowering and producing seed at most trials age 5 - 7.

E. globoidea – White stringybark

Eucalyptus globoidea was used in Australia for general construction due to its class 2 durable straight grained light brown occasionally light pink heartwood (Boland et al. 2006). *Eucalyptus globoidea* is found throughout eastern New South Wales except the far north, and eastern Victoria. On optimal sites it can reach heights of 25 – 30m and 1m diameter (Boland et al. 2006). It favours a warm humid to sub-humid climate without major extremes but can withstand some frost and snow at higher altitudes. While it grows in a wide range of soils including those derived from sedimentary slates and shales also sandstones, it prefers deep loams and clay subsoils with good drainage (Hall et al. 1963).

It was an early introduction to New Zealand with many older farm forestry plantings in Northern regions and an impressive stand at Little River on Banks Peninsula, Canterbury that is now over 100 years old. The former NZ Forest Service successfully planted several stands in their Bay of Plenty and Northland forests. It was popular with some farm foresters and was one of the eucalypt species recommended by Neil Barr. Fourteen permanent sample plots of *E. globoidea* are located from Northland to Canterbury in the Scion data base planted in farm forestry woodlots from 1980-2000. It was also one of the more successful species in three formal trials deployed in the Wairarapa and Hawkes Bay in 1975 and in Manawatu in 1982 that demonstrated its consistent performance compared to some other durable species.

In 2003, Scion established a network of nine durable eucalypt trials through the North Island and Marlborough. In these trials *E. globoidea* was one of the most successful species across many sites (Nicholas 2008). This was also the outcome of the large number of small trials planted in 2004/05 by the Eucalypt Action Group members of the New Zealand Farm Forestry Association that tested *E. globoidea,* along with 10 other eucalypt species.

There have been many examples of successful processing and use of New Zealand grown *E. globoidea.* A graveyard trial of New Zealand-grown timber reported class 2 'in ground' durability (Page et al. 1997) and a sawing study comparing four eucalypt species at age 25 years reported that *E. globoidea* was as good or better than other stringybark species evaluated (Jones et al.Hawkes 2010).

The Marlborough regional trials planted from 2003 to 2007 included this species and it demonstrated good survival and early growth. There had been no formal New Zealand or international breeding programme for this species, so NZDFI established a breeding population in 2011. Seed collected from 160 families of *E. globoidea* in native forests in Australia and from New Zealand stands growing in the Bay of Plenty and Banks Peninsula were planted in three progeny trials.

Extensive growth and form assessments and heartwood quality studies (Iyiola et al. 2022) have been completed in these progeny trials. The breeding values calculated for the key selection traits were used to identify the best performing families. Elite trees that have been grafted and established in a small clonal seed orchard by Proseed Ltd. are providing genetically superior seedlots along with collection from elite families in all three progeny trials.

Early assessments in both progeny trials and demonstration trials recorded good survival, early growth and wide site adaptability. Seedlings have grown rapidly on sheltered, higher rainfall and fertile sites however moderate frosts and waterlogged soils resulted in total failure at one site.

The MTHMAI measured in the demonstration trials is 1.3m, 0.2m higher than any NZDFI species. The highest productivity was on Hawkes Bay sites with limestone derived soils and sites with higher rainfall and pumice soils. On sites with low rainfall (under 600mm), productivity is significantly reduced. The NZDFI South Island trials are on drier and cooler sites than those in Hawkes Bay, Gisborne and Central North Island.

E. globoidea has not been heavily browsed by insect pests at any trial sites and was reported least affected by the eucalypt variegated beetle in a study of 11 species planted at three Hawkes Bay sites (Lin, 2017).

Myrtle rust is a potential health risk for *E. globoidea* and infections have occurred in nurseries but it has not been observed in any NZDFI trials.

The early and abundant floral and seed development of *E. globoidea* is an advantage for rapid advancement of the breeding population and the supply of improved seed.

Across all of these trials and in NZDFI's progeny trials, this species has displayed a variety of leaf and stem phenotypes. Single, double and multi leader stems occur in the seedlots planted in trials but selection in the breeding programme will improve stem form in the seedlots produced in clonal and seedling seed orchards.

The SWP programme has supported NZDFI to collaborate with local processors to successfully develop and test *E. globoidea* products and associated technologies, including posts, poles, veneer and LVL utilising logs of young trees from trees planted in the Marlborough 2003-2007 trials. (See Appendix 1 for relevant Technical Reports). A growth model and stem taper function have been developed (Salekin et al. 2020, Boczniewicz et al. 2022).

E. macrorhyncha – Red stringybark

Eucalyptus machrorhyncha has one of the greatest natural distributions of a stringybark, being found on the western and southern slopes of the Great Dividing Range in NSW and on the northern slopes and foothills throughout inland Victoria. (Hall et al. 1963). In many of these areas it's attractive durable pink-brown timber has seen it locally used for general construction and fencing. On optimal sites it can reach 35m in height and a diameter of 1m diameter (Boland et al. 2006).

It is adapted to a wide range of climates including winter frost and snow at higher altitudes and summer droughts and heat waves in lowland regions. It grows in soils derived from sandstones, mudstones, slates and granites all of which are well drained (Hall et al. 1963).
There is no recent Australian research or international plantation use known of this species.

There are few known mature stands of *E. macrorhyncha* in New Zealand. It was included in the 2003 Scion trials; the NZFFA 2004/05 trial series and the Marlborough regional trials planted from 2003 to 2007. Generally it had demonstrated good survival and modest growth in these trials. *E. macrorhyncha* was selected for NZDFI's demonstration trials based on its potential wide adaptability particularly for colder dry New Zealand environments.

In 2005, under a local joint venture between Proseed NZ, Vineyard Timbers and Marlborough Regional Forests a seed stand was planted in Marlborough with a mix of 6 provenance seedlots. *E. macrorhyncha* was selected for NZDFI's demonstration trials based on its potential wide adaptability particularly for colder dry New Zealand environments. Seed was collected from the best trees growing in that stand and deployed in the 2013 and 2018 demonstration trials.

The *E. macrorhyncha* in the demonstration trials reinforced this species' site adaptability, consistent high survival and early growth following planting. The exceptions were a few losses due to severe frosts and in one site with waterlogged soils (probably combined with frost) resulted in total failure.

The NZDFI demonstrations trials recorded an average MTHMAI 1.1m only 0.2m lower than *E. globoidea*. These results demonstrate the species is capable of moderately productive growth rates in dry, cold and exposed sites with high rainfall. Highest productivity was in Taumaranui followed by Hawkes Bay sites and those located in pumice soils at Lake Taupo.

Across all of these trials and in the Waikakaho seed stand, this species displays a variety of form and branching architecture. *E. macrorhyncha* is self-pruning and the best trees have developed straight single leader stems and have shed all branches from two thirds of the stem and formed a very light crown of well-spaced branches. This has encouraged productive grass growth under the canopy which can be managed for grazing.

E. macrorhyncha was reported least affected by eucalypt variegated beetle in the Hawkes Bay study of 11 species (Lin, 2017). Some individuals started flowering and producing seed in several trials age 5 – 7. Most individuals in the Marlborough 2005 seed stand have flowered.

E. macrorhyncha has encouraging prospects to extend plantings in dry and cold regional environments and further research is underway to advance knowledge of the species.

Class 1 - 2 Red Heartwood Species

E. argophloia – Queensland white gum

The natural range of *E. argophloia* is very small and confined to the flatlands with moderately fertile soils in southern Queensland. Most of the natural stands were cleared for agriculture and the durable dark red brown hardwood was used for fencing and general construction. *E. argopholia* can grow to 40 m tall with a diameter of up to 1.5m (Boland et al. 2006) where the annual rainfall is 650-700mm with summers hot and winters short with some frosts.

E. argopholia was identified as 'vulnerable' under the *Queensland Nature Conservation Act 1992* with no harvesting permitted of remaining endemic forest. It was selected by Queensland's Department of Agriculture, Fisheries and Forestry for a breeding programme to encourage plantation development and by 2013, there were 4,000 hectares established in Queensland's subtropics in drier, inland areas where rainfall averages less than 1000mm a year (DAFF 2013).

There are no known mature stands in New Zealand nor any record of it being tested by farm foresters or researchers. NZDFI obtained seedlots from the Department of Primary Industries, Queensland and included *E. argopholia* as a secondary species for its breeding programme. *E. argophloia* has a rich red timber and the objective was to hybridise with *E. bosistoana* as the two species, while widely separate in natural distribution have similar taxonomic characteristics (Boland et al. 2006).

In 2011 NZDFI planted three progeny trials with seed from 18 families sourced from DPI. Only one of these trials has been assessed, one has been abandoned after almost total failure due to poor drainage and the third has good survival but with very slow growth.

E. argophloia was only deployed in five of NZDFI's 2011 demonstration trials due to limited seedling production. Early growth and poor survival on some sites were not encouraging when compared to other class 1 species in the trials. While assessments were continued, it was not planted in later trials except at the Macbeth site due to the interest of the landowner.

The results recorded in NZDFI demonstrations trials produce an average MTHMAI of 0.8m that is on a par with *E. notablis* but generally lower by 0.2m than other class 1 red species on most sites. Across all of these trials and in the Waikakaho seed stand, this species has a variety of form and branching architecture with some single leader stems but also double and multi leader stems. The best trees have developed straight single leader stems and have started to shed lower branches with a light crown developing well-spaced branches. The combination of their small greyish green foliage and white straight trunks produces an attractive amenity species.

A few trees at one trial site have been recorded flowering and producing seed.

E. camaldulensis – Red river gum

The most widely distributed of all the eucalypts, *E. camaldulensis* is also one of the most variable. There were once vast natural stands with the largest remaining found along the banks and flood plains of the Murray-Darling river system that runs through inland south- eastern Australia. Trees were felled for the hard durable red coloured hardwood suitable for heavy construction, railway sleepers and charcoal (Baker 1906). Much of the harvesting was from the forests which can still be seen growing along the vast Murray River system.

E. camaldulensis generally grows to 20m but can reach to 45m, with diameters of 1-2m common (Boland et al. 2006). It covers an extensive network of river and creek systems throughout much of the dry regions of Australia from tropical to temperate environments. In temperate regions with annual rainfall 250-600mm, summers are hot and winters can be severe with heavy frosts. Soils are alluvial and derived from various parent material including volcanic and sedimentary sources (Hall et al. 1963).

E. camaldulensis was one of the earliest species to be planted internationally due to genetic diversity offering broad adaptation to both temperate and tropical climates. It has become one of the most widely planted forestry species in arid and semi-arid regions around the world and been included in many breeding programmes; successfully cloned and hybridized with other species.

It was an early introduction into New Zealand and widespread planting on farms by early settlers was successful in the drier regions of Hawkes Bay, Wairarapa, Marlborough and Canterbury with large old trees still standing today. There was a renewal of interest in the 1980s for firewood planting but other species with greater productivity and tolerance of insect pests were more successful.

NZDFI selected *E. camaldulensis* for the demonstration trials based on its extensive international use in plantations in dry regions and potential adaptability particularly for colder dry New Zealand environments. A west Australian seed orchard seedlot was planted in the trials.

Early assessments of the success of *E. camaldulensis* in the demonstration trials revealed this species could be successfully established. But growth rates between sites have been highly variable and difficult to interpret as the species is heavily defoliated seasonally by insects at all sites. The tree form is also very poor with all trees having sinuous stems and most with double or multi leaders and heavy branches.

There has been no flowering recorded in any of the trees within the trials.

E. longifolia – Woollybutt

The red heartwood of *E. longifolia* is renowned for its strength and durability for a wide range of applications and has a long history of use in the NSW regions where sustainable harvest continues in some of the native forests. The natural distribution is limited to coastal forest valleys and low country with a preference for heavy alluvial and other heavy soils that are moderately well drained (Boland et al. 2006). It has adapted to a cool to moderately temperate climate, some winter frost and warm summers. Rainfall is 600-1000mm per annum and spread uniformly so there are not regular summer droughts. (Hall et al. 1963).

There is no recent Australian research or international plantation use known of this species.

There had been some early success with planting this species (Barr 1996). It was included in a small number of the Eucalypt Action Group (NZFFA) trials planted in 2004/05 and in small informal trials planted in Marlborough the same year. It's success in these trials demonstrated adaptability and productivity that encouraged planting more widely.

NZDFI selected *E. longifolia* for NZDFI's demonstration trials as it produces class 1 red coloured timber and was suited to North Island east coast environments.

The results recorded in NZDFI demonstrations trials produce an average MTHMAI of 1.0m and is similar in productivity to *E. tricarpa* on most sites. The seedlot used in the demonstration trials is from a New Zealand stand near Kerikeri. Across all of these trials this seedlot produces a straight stem but consistently has a double or multi leader habit. In unthinned blocks trees have grown very straight but still retain their lower branches. At this stage the best trees have formed an erect stem with a dense heavy crown particularly in thinned blocks or those on the edge of a trial block.

There have been several individuals recorded flowering and producing seed in only one demonstration trial.

E. notabilis – Blue mountains mahogany

E. notabilis occurs in four disjunct provenances at higher altitudes in the tablelands and ranges from southern Queensland to central NSW and typically grows to a height of 30m. It is related to *E. resinifera* (Red Mahogany) and other similar species that all produce durable dark red heartwood that was used in general construction.

There is no recent Australian research or international plantation use of this species.

There are no known mature stands in New Zealand with *E. notabilis* selected for NZDFI's demonstration trials to test its potential adaptability to North Island east coast environments.

The early survival assessments of the Australian forest seedlot of *E. notabilis* deployed in NZDFI's 2011 demonstration trials showed it to be slower growing than other species in the group in most trials. Therefore, while NZDFI did not include it in any later trials, assessments in some PSPs were continued. It has been heavily browsed by insect pests and often develops multi leader stems with heavy branching that supports a dense crown.

There has been no flowering recorded in any of the trees within the trials.

E. tricarpa – Red ironbark

E. tricarpa produces a dark red heartwood that is very hard, extremely durable and termite resistant. It is very similar to *E. sideroxylon* that is also called red ironbark. Like other durable hardwoods these two species have had a long history of use and are still sought after in regions where they occur.

E. tricarpa's natural distribution is southern NSW and throughout a number of localities from east to central Victoria where it grows to a height of 25-35m and 1m or more in diameter on undulating hill country usually in mixed forests with a number of other species including *E. bosistoana, E.globoidea* and *E. longifolia.*

There is a cool to moderately temperate climate, some winter frosts and warm summers. Rainfall is 500-1000 mm per annum and spread uniformly in the west while the drier central region experience summer droughts and heatwaves. (Boland et al. 2006).
There has been some international plantation use and research of *E. tricarpa.* In 2001 both *E. sideroxylon* and *E. tricarpa* were planted in provenance/progeny trials in Victoria and New South Wales under the ALRTIG programme.

Ironbark is a highly valued hardwood and *E. sideroxylon* was an early species to be successfully introduced into New Zealand with mature amenity and shelter trees evident throughout the drier regions of Hawkes Bay, Wairarapa, Marlborough and Canterbury.

NZDFI identified *E. tricarpa* as a secondary species for breeding and two breeding populations were established, 24 families in 2011 and 20 families in 2017. It is a class 1 durable hardwood and has potential adaptability to dry hot environments similar to the driest northern New Zealand east coast regions.

The results recorded in NZDFI demonstrations trials produce an average MTHMAI of 0.9m and is similar in productivity to *E. longifolia* on most sites. The seedlot used in 2011 was a mix of two unimproved provenance collections and was reduced to one seedlot for the 2013 and 2014 trials. Across all of these demonstration and progeny trials, this species has developed a variety of stem form and branching architecture with many double and multi leader stems. There are some trees with straight single leader stems that retain much of their lower branches with moderate branching supporting an open crown.

Since 2020, a few trees at some trial sites have been observed flowering.

Note: At the time of writing this report a new project has started to evaluate and report on the suitability of *E. argophloia, E. tricarpa* and *E. longifolia* for commercial plantation deployment in New Zealand dryland environments. This is focused on assessing growth rate and heartwood produced by these species across a wide range of these environments. While these species are renowned in Australia for producing rich red-coloured class 1 durable timber we need to learn how much heartwood they are producing and the properties of that heartwood.

RECOMMENDATIONS FOR FURTHER RESEARCH

This report presents the current knowledge of tree growth and site adaptability for the eleven species tested in the demonstration trial series planted 2011 – 2014 and from data collected in 2020-2022.

These results will assist forest growers and farm foresters to select the best species and sites to optimise the productivity and value of the tree crop.

Over the past 12 years NZDFI's research activities have been spread over a wide range of species. While all species are different, the research and development requirements to optimise productivity, health and wood properties are similar. The scope of research required for each species is significant.

Data collection and model development

The NZDFI has restricted the number of species for genetic improvement, concentrating efforts and resources on a few promising candidates. Further sites were established in 2016, 2018 and 2021 with a much-reduced list of species and seedlots. These trials include up to six species, *E.bosistoana, E. globoidea, E. quadrangulata, E.tricarpa, E. macrorhyncha* and *E. cladocalyx* and contain the first genetically improved seedlots and clones produced by the breeding programme. These genetic gain trials are used to provide a ranking and long-term evaluation of the performance of the different sources of genetic material for short rotation post/pole regimes; medium rotation sawlog regimes and long- term permanent carbon forests.

The measurements from the network of permanent sample plots (PSPs) within these trials are the framework for accurate growth and yield modelling.

Ideally measurements will include intensive soil sampling to provide detailed soil mapping of all NZDFI sites that will assist with understanding the significant annual height increment differences among the species within- and between-sites. Hybrid physiological and mensurational models that employ the climatic, soils, and topographical data for each site can be developed.

Further research requirements are:

- remeasure of PSPs and PSP establishment in the trials planted in 2016, 2018 and 2021
- review and remeasure the 2011, 2013 and 2014 demonstration trial PSPs not remeasured in 2020-2022 programme
- distil entries in the current Katmandoo database as meta data for ongoing analyses
- modelling of biomass, improvement of taper and volume functions, and growth and yield model improvement
- microsite evaluation of soils and sites in demonstration trials for physiological and mensurational models
- establish a comprehensive silvlcultural trial programme, exploring a range of pruning and thinning options on diverse sites
- analysis, reporting and transfer of new knowledge to growers.

As older trials are thinned by landowners, the stem taper of fallen trees can be measured and the data used to develop taper functions for the key NZDFI species. The heartwood percentage up the stem can also be measured and total biomass productivity assessed.

Breeding population development

E. globoidea has proven to be highly productive, adapted to sheltered sites with moderate to high rainfall, resistant to severe insect browsing and produces wood with properties suitable for a range of end uses. The breeding population of *E. globoidea* can be advanced to a 2nd generation by selecting and collecting seed from the progeny trials established in 2011.

E. macrorhyncha has encouraging prospects to extend plantings in dry and cold regional environments and further research is underway to advance knowledge of the species. Tree productivity, form, and heartwood properties across up to 25 NZDFI trial sites are being measured and seed collected from plus tree candidates for the establishment of a 1st generation breeding population.

The *E. bosistoana* breeding populations and 2018 genetic gain trials have been confounded with the unintentional inclusion of *E. melliodora.* The families planted in the breeding populations have been genotyped (Kim, 2023) and the dataset derived from this can be used to further knowledge of the taxonomic identity and genetic diversity.

Further work is required to:

- identify New Zealand genetic resources and initiate seed collections from forest stands in Australian for a breeding programme
- develop a breeding plan
- extend the use of genomics to derive informed pedigree and relationship information in the breeding populations, and the seedlots with improved genetics being deployed for plantations
- review known *E. macrorhyncha* biological risks in New Zealand and Australia.

ACKNOWLEDGEMENTS

NZDFI's demonstration trial network has been established, maintained and measured with significant ongoing support of the landowners that provide our trial sites. This includes farm foresters, forest growers, trusts, district and regional councils. Our R&D programme is only possible because of their interest and long-term commitment.

We also acknowledge the generous support of the organisations that financially contributed to establishment of our trial network and PSP measurement programme including:

- the NZDFI partners; Proseed NZ, University of Canterbury and Marlborough Research Centre Trust
- the Ministry of Primary Industries Sustainable Farming Fund
- the MBIE/FGR Specialty Wood Products programme and its industry partners
- NZ Farm Forestry Association Eucalypt Action Group and Neil Barr Farm Forestry Foundation.

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SWP-T121	C. Altaner (2021) Recommended sampling intensity for phenotyping durable eucalypt heartwood quality	Breeding
SWP-T123	D Boczniewicz, P Millen, C Altaner (2021) Feasibility trials - peeling posts of durable eucalypts	Processing
SWP-T124	C. Altaner (2021) Assessing heartwood in *E. bosistoana* cores from NIR hyperimages	Breeding
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SWP-T127	P Hall, R. Sargent (2021 Techno-economic analysis of posts from specialty wood species and radiata pine	Processing
SWP-T131	V Ghildiyal, C Altaner (2021) Assessment of *Eucalyptus globoidea* heartwood at Avery	Growing
SWP-T132	J van der Waals, I Simpson, T Singh (2021) The decay resistance of six *Eucalyptus* species after four years exposure	Durability
SWP-T134	D. Boczniewicz, E. Mason, J. Morgenroth (2021) Developing fully compatible taper and volume equations for all stem components of *E globoidea* Blakely trees in NZ	Growing
SWP-T140	L Mann, S Pawson (2022) *Eucalyptus* resistance to paropsine beetles	Pests and diseases
SWP -T142	M Sharma, C Altaner (2022) Assessment of *E. globoidea* heartwood at Ngaumu	Growing
SWP-T144	M Sharma, C Altaner (2022) Assessment of *E quadrangulata* breeding populations	Breeding
SWP-T152	V. Gildiyahl, C. Altaner (2022) Genetic variation in collapse and other wood properties of *E. quadrangulata* at mid-rotation age	Breeding/processing
SWP-T153	L Mann, J Morgenroth, C. Xu, and S Pawson (2022) Assessing paropsine damage on E*ucalyptus* trees with remote sensing	Pests and diseases
SWP-T155	H. Scown & C. Altaner (2023) Machinability of 28-year-old *E. globoidea* wood	Processing
SWP-T156	M. Sharma, C. Altaner (2023) Assessment of NZDFI's 2016 *E. quadrangulata* breeding population at NZRC Paparoa	Breeding
SWP-T157	V. Ghildiyal, C. Altaner (2023) Assessment of *E. globoidea* heartwood at Avery	Growing
SWP-T168	C. Altaner (2023) Genetic structure and diversity in the NZDFI *Eucalyptus bosistoana* and *E. argophloia* breeding populations	Breeding

APPENDICES

Appendix 1: NZDFI Demonstration trials 2010-2018 – Genetic Seed Sources

Species	Seed Source	2011	2013	2014	2018
E. argophloia	SSO Narromine	√		√	
E. bosistoana	Native stand collection. Top families from 2009/10 trials	√			√
	Proseed Seedlot 11/740, Cann River		√	√	
	Cuttings from clones ex Woodville Trials				√
	Seedlot 16/619 Gippsland				√
E. camaldulensis	WAFPC SO	√	√	√	
E. cladocalyx	SSO Hamilton VIC	√	√	√	√
E. eugenioides	ATSC Sydney District	√			
E. globoidea	Cann River	√	√	√	√
	Yadboro SF	√			
	Purerua		√		
	Waikakaho Provenance Seed Stand				√
E. longifolia	Proseed Seedlot 09/738, Kerikeri	√		√	
E. macrorhyncha	Gunning NSW	√		√	
	Stromlo Forest	√		√	
	Uriarra Road	√		√	
	Waikakaho Seed Stand Seedlot 17/642		√		√
E. notabilis	Lake Burragorang	√			
E. quadrangulata	Mt Skanzi	√	√	√	
	Native stand collection. Mixed family seedlot from 2016 trial Seedlot 17/641				√
E. tricarpa	Tucker Box	√	√	√	
	Martins Creek	√			
	Native stand collection. Mixed family seedlot				√

Appendix 2: Trial site details

Trial description														Silvicultural		PSPs and status				Environmental					
Site ID	Site name	Region	Easting	Northing	Year planted	Site description	Site prep	Number of species	Total blocks planted	Trial spacing (m)	Trees per block	Trees per site	Surrounding vegetation	Thinned	Pruned	Event	PSPs established	PSPs measured 2020-2022	PSP status	Frost-free days	Rainfall	Feb max	July min	Altitude	Base Geology
58	Wishart-Cribb	Gisborne	2009766	5738024	2010	Grass cover; moderate to steep slope	Pre plant spot spray	4	7	2.8 x 2.8	49	343	Eucalypt forest	No	No		7	0	Check for re measurement	269	1136	23	3	204	sandstone
71	Paton	Greater Wellington	1791465	5423414	2010	Grass cover; flat	Pre plant spot spray	4	12	3.3 x 2.5	49	588	Eucalypt forest	No	Yes		12	0	Check for re measurement	261	915	21	3	70	gravel
54	Dillon	Marlborough	1656217	5389133	2011	Grass cover; flat to moderate slope	Pre plant spot spray	11	33	2.8 x 2.8	49	1617	Grassland	No	No	Frost post planting	30	28	Continue measurement	183	692	23	0	249	gravel
56	Martin	Canterbury	1571896	5217535	2011	Grass cover; flat	Pre plant spot spray	11	36	2.8 x 2.8	49	1764	Grassland	No	Yes	Waterlogged post planting	34	16	Continue measurement	268	699	22	2	92	gravel
58	Wishart-Cribb	Gisborne	2009766	5738024	2011	Grass cover; moderate to steep slope	Pre plant spot spray	11	32	2.8 x 2.8	49	1568	Eucalypt forest	No	No		32	25	Continue measurement	269	1136	23	3	204	sandstone
59	Alexander	Hawkes Bay	1911531	5607385	2011	Grass cover; easy to moderate slope	Pre plant spot spray	11	38	2.8 x 2.8	49	1862	Grassland	Yes	Yes	Frost post planting	29	25	Continue measurement	239	808	23	3	129	limestone
61	Trimble Foundation	Greater Wellington	1846079	5465273	2011	Grass cover; flat	Pre plant spot spray	11	33	2.8 x 2.8	49	1617	Grassland	No	No	Waterlogged post planting	32	0	Check for re measurement	258	1006	22	3	214	gravel
65	Tect Park	Bay of Plenty	1876146	5795487	2011	Pine cutover; flat to easy slope	Pre plant aerial spray	11	29	2.8 x 2.8	49	1421	Mixed Species	No	No	Waterlogged; weed competition; insect browse	29	0	Abandoned	268	2260	21	3	505	ignimbrite
67	Saggers	Marlborough	1675952	5399353	2011	Grass cover; easy to moderate slope	Pre plant spot spray	11	32	2.8 x 2.8	49	1568	Grassland	Yes	No		32	32	Continue measurement	192	678	23	1	103	conglomer
68	NZCF	Greater Wellington	1873075	5491156	2011	Grass cover; easy to moderate slope	Pre plant spot spray	11	32	2.8 x 2,8	49	1568	Eucalypt forest	No	No	Severe deer browse	23	0	Check for re measurement	256	1399	21	5	218	greywacke
70	McNeill	Hawkes Bay	1939989	5588123	2011	Grass cover; flat	Pre plant spot spray	11	28	2.8 x 2.8	49	1372	Grassland	No	No		28	20	Continue measurement	271	1061	22	2	265	limestone
72	JNL Totara	Gisborne	2047965	5733006	2011	Grass cover; easy slope	Pre plant aerial spray	11	29	2.8 x 2.8	49	1421	Grassland	No	No	Severe deer browse	13	0	Abandoned	271	1566	22	4	414	mudstone
74	JNL Steed	Hawkes Bay	1994303	5672398	2012	Grass cover; flat	Pre plant aerial spray	6	18	2.8 x 2.8	49	882	Grassland	No	No	Grass competition; severe goat browse	12	6	Continue measurement	287	1633	23	4	19	gravel
57	Lissaman	Marlborough	1681458	5380301	2013	Grass cover; easy to moderate slope	Pre plant spot spray	6	12	2.8 x 2.8	100	1200	Grassland	No	Yes		12	12	Continue measurement	214	727	22	1	233	conglomer
75	NZRC Okota	Horizons	1823625	5584212	2013	Grass cover; easy to moderate slope	Pre plant spot spray	4	7	2.8 x 2.8	100	700	Eucalypt forest	No	No	Severe deer browse	4	4	Continue measurement	251	993	22	2	396	mudstone
76	Williams	Greater Wellington	1834752	5456394	2013	Grass cover; moderate slope	Post plant spot spray	5	15	2.8 x 2.8	100	1500	Eucalypt forest	No	Yes		15	12	Continue measurement	233	972	22	2	195	mudstone
77	Chamberlain	Canterbury	1583246	5230206	2013	Pine cutover; easy to moderate slope	Pre plant aerial spray	6	12	2.8 x 2.8	100	1200	?	No	No	Grass/weed competition post planting	10	0	Check for re measurement	221	674	22	1	472	sandstone
20	LTFT Mission Bay	Waikato	1861798	5687274	2014	Pine cutover; moderate slope	Pre plant aerial spray	8	16	2.8 x 2.8	100	1600	Pine forest	No	No	Frost post planting	10	9	Continue measurement	227	1339	21	1	647	ignimbrite
24	Saathof	Hawkes Bay	1909126	5614943	2014	Grass cover; steep knob	Pre plant spot spray	5	10	2.8 x 2.8	100	1000	Eucalypt forest	No	Yes	Two failed blocks replanted 2015	10	10	Continue measurement	251	959	23	3	171	limestone
25	HBRC Waihapua	Hawkes Bay	1934028	5648322	2014	Grass cover; easy to moderate slope	Pre plant spot spray	8	25	2.3 x 2.3 & 2.8 x 2.8	100	2500	Eucalypt forest	Yes	Yes		25	24	Continue measurement	263	1484	22	4	260	breccia
26	NZRC Paparoa	Horizons	1785613	5685723	2014	Grass cover; flat to easy slope	Pre plant spot spray	8	12	2.8 x 2.8	100	1200	Redwood forest	No	No		12	9	Continue measurement	256	1563	24	2	153	sandstone
27	Clifton	Tasman	1592321	5446891	2014	Grass cover; flat to easy slope	Pre plant spot spray	8	16	2.8 x 2.9	100	1600	Grassland	No	No		3	0	Check for re measurement	264	1440	20	0	472	granite
28	MacBeth	Canterbury	1614499	5263352	2014	Grass cover; moderate slope	Pre plant spot spray	9	9	2.3 x 2.3	100	900	Eucalypt forest	Yes	Yes	Drought post planting	9	9	Continue measurement	231	809	22	0	151	siltstone
29	Phoebe Plains	Canterbury	1619842	5266527	2014	Grass cover; flat	Pre plant spot spray	7	7	2.3 x 2.3	100	700	Grassland	No	No	Frost & drought post planting	7	0	Check for re measurement	210	758	22	0	53	gravel
75	NZRC Okota	Horizons	1823625	5584212	2014	Grass cover; easy to moderate slope	Pre plant spot spray	7	13	2.8 x 2.8	100	1300	Redwood forest	No	No	Severe deer browse	7	7	Continue measurement	251	993	22	2	396	mudstone
26	NZRC Paparoa	Horizons	1785613	5685723	2018	Grass cover; flat to moderate slope	Pre plant spot spray	4	18	2.8 x 2.8	100	1800	Eucalypt forest	No	Yes		18	18	Continue measurement	256	1563	24	2	153	sandstone
35	Landcorp Kapiro	Northland	1682193	6111552	2018	Grass cover & old pine cutover; easy slope	Pre plant aerial spray	4	15	2.3 x 2.3	100	1500	Eucalypt forest	No	Yes		15	15	Continue measurement	365	1601	23	7	161	basalt
36	Landcorp Omamari	Northland	1667365	6026607	2018	Grass cover; moderate to steep slope	Pre plant aerial spray	5	19	2.8 x 2.8	100	1900	Grassland	No	No		18	18	Continue measurement	364	1209	24	6	95	sandstone
37	Thomson	Taranaki	1714266	5652642	2018	Pine cutover; moderate slope	Pre plant aerial spray	5	10	2.8 x 2.8	100	1000	Eucalypt/pine forest	No	No	Grass/weed competition post planting	8	8	Continue measurement	235	2116	21	3	220	sandstone
38	Landcorp Edenham	Hawkes Bay	1924532	5570402	2018	Pine cutover; moderate slope	Pre plant aerial spray	6	24	2.3 x 2.3	100	2400	Eucalypt forest	No	Yes	Frost post planting	16	16	Continue measurement	251	1156	22	2	184	gravel
39	LTFT Rotopuha	Waikato	1866688	5694389	2018	Pine cutover; flat to easy slope	Pre plant aerial spray	4	21	2.8 x 2.8	100	2100	Pine forest	No	No	Frost post planting	10	10	Continue measurement	185	1230	21	1	565	ignimbrite
41	Timberlands Rotoehu	Bay of Plenty	1911237	5788789	2018	Pine cutover; moderate slope	Pre plant aerial spray	4	18	variable	100	1800	Eucalypt forest	No	No		18	18	Continue measurement	351	2035	22	1	331	rhyolite
54	Dillon	Marlborough	1656217	5389133	2018	Grass cover; moderate slope	Pre plant spot spray	6	21	2.8 x 2.8	100	2100	Grassland	No	No	Frost post planting	20	20	Continue measurement	183	692	23	0	249	gravel
									659			**47591**					**560**	**371**							