TRIG FINAL REPORT-TREE BREEDING AND SEED PRODUCTION (2 OF 3)

Trials Review, Information and Genetics Project

Forestry Australia

Project Period: 01 March 2022 – 31 May 2023

Prepared by: Dr Phil Lacy
16/05/2023

Author Signature	
Author Name	Phil Lacy
Author Role	Research and Consulting Forester
Date	16 May 2023

Co-author	
Name	Erin Hodgson
Role	Consulting Forester
Date	16 May 2023

Co-author	
Name	Andrew Callister
Role	Director (Treehouse Consulting)
Date	16 May 2023

Reviewed By	
Name	Allie Muneri
Role	Research Projects Manager
Date	16 May 2023

Disclaimer

This document has been prepared by PF Olsen Limited specifically for the purposes stated in the document and is for your information only. PF Olsen Limited has used reasonable endeavours to ensure that the data and any other information in the document including any estimates, quotes, valuations and analyses is based on reliable sources and, where applicable, industry appropriate methodology and software.

Although the information in this document is provided in good faith, PF Olsen Limited does not make any express or implied representations or give any warranties or guarantees as to the accuracy or completeness of the information. PF Olsen Limited does not accept liability for any claim, action, cost, loss or damage arising directly or indirectly from use or reliance on the information in this document and you agree to indemnify PF Olsen Limited against any losses, damages, costs, liabilities or expenses in relation to claims or disputes incurred as a result of you using or acting in reliance on the information in this document.

Acknowledgements

We acknowledge the support and feedback from the TRIG Project Steering Committee:

- Dr Kevin Harding (Chair)
- Liam Costello (Dept. of Energy, Environment and Climate Action, Victoria)
- Jacquie Martin (Forestry Australia)
- Jan Newport (Forestry Australia)
- Philippa Noble (Farm Forest Growers Victoria)
- Andrew Lang (Farm Forest Growers Victoria)
- Dr Andrew Walpole (Farm Forest Growers Victoria)

We also acknowledge support from the following people and organisations:

- Vic Forests
  - Trevor Nicklen
  - Wally Notman
  - Robert Chewe
  - Peter Jenkins
- Keith Cumming (Arborline)
- Rod Bird
- Dr David Bush (CSIRO)

TABLE OF CONTENTS

1. TRIG project introduction

1.1 Background

The Trials Review, Information and Genetics (TRIG) project was designed in consultation with Farm Forest Growers Victoria, with funding provided by the Federal Government, and delivered via the Victorian Government's Department of Jobs, Precincts and Regions (DJPR). Forestry Australia, in its project oversight role, engaged PF Olsen to project manage and deliver the TRIG Project.

1.2 Purpose

The purpose of the TRIG Project is to support the integration of tree plantings into farms in Victoria through four key activities:

1. Provide a comprehensive update to the farm forestry trial database information and identify priority sites to target for ongoing treatment and data collection.

2. Identify model plantings of various species/provenances that have performed well in representative environments. Where appropriate, and in conjunction with the landowners, plan and manage approved stand management activities (such as thinning).

3. Enhance the management of existing seed orchards and explore establishment of new seed production areas (SPAs) and identify the need for the establishment of new seed orchards and SPAs to supply improved seed.

4. Collate, clean and disseminate relevant updated datasets, reports and advisory information via a publicly accessible web platform hosted by the Victorian government and Forestry Australia and other promotional activities.

2. Sub report introduction

This sub report has been separated out from the main report, for ease of reading. This section covers the tree breeding and seed production in Victoria and the implications for Farm Forestry and small growers.

3. Introduction to tree breeding and seed production systems

An important aspect in the long-term development of commercial tree plantations is the selection and improvement of genetically superior material for deployment to commercial plantings. This section provides a brief overview of what tree breeding involves, and how seed production systems can be implemented.

3.1 Tree breeding

The modern era of tree breeding and improvement dates back to the 1950's, with the initiation of multiple large-scale programs around the world (Zobel & Talbert, 1984). Tree breeding programs share many similarities in structure, information flow, and strategy, despite large biological differences among species.

Provenance tests usually provide the first indications of large-scale genetic variation in commercially important traits (such as growth rate, straightness, and branch size), often simultaneously offering valuable early estimates of a species' growth potential in the target environment. Family-in-provenance tests typically follow, commencing the process of tree selection, perhaps targeting provenances that were identified at the previous step. The population of native trees and other unimproved individuals from which seed were collected may be referred to as the breeding program's 'founder population' (F0). It is important that the founder population be as genetically diverse as possible, to sustain multiple generations of selection and improvement without exhausting useful genetic variance.

The complete first generation (F1) of tested progeny constitutes the first 'base population' of a breeding program (see Figure 1 and Figure 2). Genetic selection amongst this base population results in a 'selected population', which then parents the next (F2) generation, and so the cycle of reciprocal selection and breeding continues (Figure 1). Each generation is composed of a broad base population and a narrower selected population (Figure 2). A more elite 'propagation population' may be formed at each generation for the purpose of deploying the best genetics to plantations. Seed-based deployment options are presented in Section 3.2 of this report.

Effective identification of the best base population individuals for inclusion in the selected population requires information about genetic relatedness and reliable measures of individual performance (the individuals' appearance, or 'phenotype'). Relationship information is traditionally derived from the informed pedigree, though more recently genomic relationship information is used whenever individuals have been genotyped. Phenotype information is obtained directly from trial measurements and its integrity depends on well-designed tests and precisely implemented field practices. Relationship and phenotype data are combined in statistical models to best estimate the genetic and non-genetic (i.e. environmental) variances controlling each trait, and the genetic values of each parent and progeny.

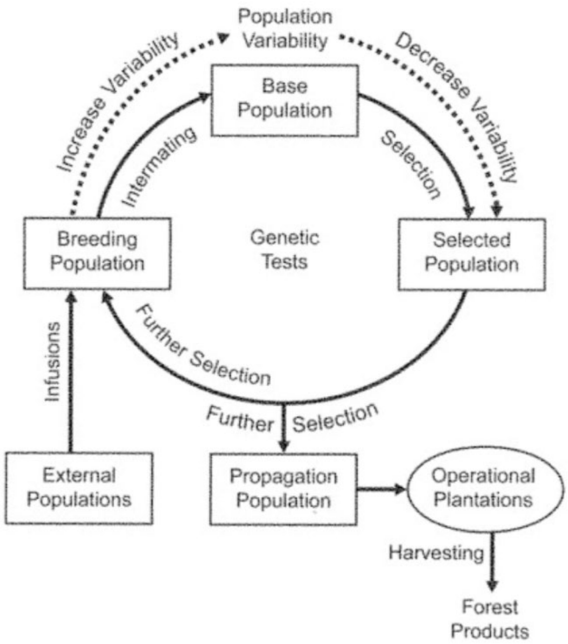

Figure 1- The breeding cycle of tree improvement programs. Each of the core population types shown in the inner circle are formed once per cycle of improvement in the sequence shown, while other population types may or may not be formed. (Reprint of Figure 11.1 from White et al. 2007)

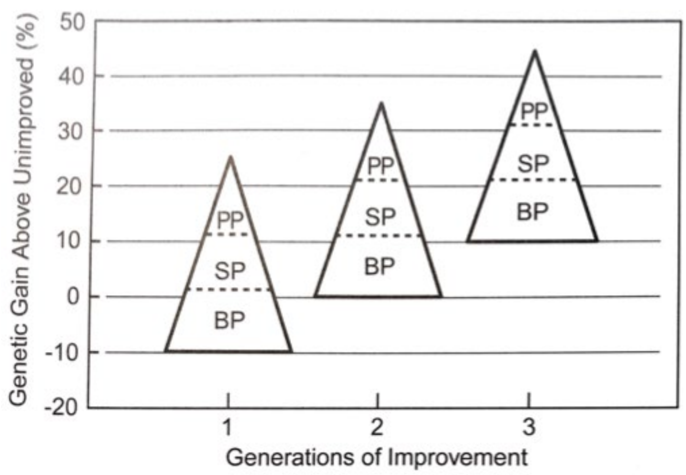

Figure 2- Schematic diagram showing genetic gains for three population types in each of three different cycles of improvement. The entire triangle represents the base population (BP) for each generation. The next smallest triangle represents the portion of the BP that is the selected population (SP), while the upper triangle is the propagation population (PP). Genetic gains are expressed above a starting point of 0% for the unimproved species (i.e. BP in generation 1). The area of each population type inside the triangle is proportional to its size (number of individuals) and diversity, while its height on the y axis expresses the mean genetic value for that population type. (Reprint of Figure 11.2 from White et al. 2007)

Choosing amongst options for implementing genetic selection requires a good knowledge of how the measured traits impact on the commercial value of the tree crop. For example, a species domesticated for pulp and paper production will be improved with greater pulp yield and more optimal wood density, while a species used for sawlog production will be improved with greater stem straightness, smaller branching, and wood properties that confer improved lumber properties. Increased growth rate is a goal in every case. Genetic selection can then proceed by a simple option of independent culling, where a selected individual must surpass pre-determined thresholds for each trait independently. Alternatively, the selection and propagation populations can be determined using a selection index, which is formed by applying commercial weights to the genetic values of each trait (Cotterill & Dean, 1990). In each case, the genetic gain achievable (at a given genetic diversity) decreases with each additional trait that is included in the selection criterion. The selection index approach is popular for tree breeding as it integrates all the genetic information in the most theoretically optimal way. However, if more flexibility is required of the propagation population then multiple sublines can be developed, each with strengths in particular combinations of attributes.

Sublining is a common response to genotype-environment interaction (GxE), which presents a challenge to tree breeders when it appears within the region(s) targeted by a particular tree improvement program. GxE is only identified after sufficient progeny trials have been established and assessed to show that genetic performance (especially ranking) varies in a predictable fashion from one type of environment to another. In this case, growth in each defined environment is typically considered as an individual trait, and a population subline can be developed for each environment.

3.2 Seed production systems

Commercial seed production is a critical step in realising genetic gains from tree improvement programs. Seed production facilities vary widely in complexity, cost, and capacity to deliver genetic gains. It is therefore important to customise the seed production strategy by considering the expected demand for seed in terms of volume and revenue, as well as the level of genetic improvement in material available for deployment.

At the simplest level, seed production areas (SPAs) are genetically unimproved stands that are used for seed collection, sometimes supported by proven performance of their seed in formal tests. Provenance trials can also be converted into SPAs. Often SPAs are heavily thinned to remove slower growing and poorly formed individuals before they can pass on their genes to the next generation. SPAs are usually employed at the earliest stage of genetic improvement before formal progeny tests have identified individuals with superior breeding values. They may also be preferred when expected seed demand is insufficient to warrant the additional costs of establishing and maintaining an orchard of selected, progeny-tested trees. A local SPA example is the *E. cladocalyx* production area at Kersbrook in South Australia (Harwood, et al., 2007).

A seed orchard is typically constituted of trees that have been progeny tested. Progeny testing is a fundamental activity in tree improvement, which involves planting collections of seed from known parents (families) in separate plots to identify the breeding values of parents and progeny alike. The breeding value of any first-generation progeny is determined partly by the tree's own performance and partly by the performance of its siblings (sibs) planted in the same plot and in other plots around the trial network. The breeding value of advanced-generation progeny is further influenced by the performance of all its relatives across multiple generations of genetically linked field trials. Breeding values are important measures of an individual's worth in a seed orchard because they are the best predictors of the genetic performance of its seed.

Seedling seed orchards (SSOs) are often established by converting a progeny test into an orchard through selective thinning to remove the poorest performing trees (rogueing). An efficient SSO establishment strategy is to plant a network of highly connected progeny trials across the most common environments in the target planting zone, plus one progeny trial in a location that is convenient for seed production. The breeding values of individual trees within the progeny trial-cum-SSO (PT-SSO) will be calculated based on their own individual measurements (phenotypes) and the performance of their sibs across the network of trials. The PT-SSO is then rogued to completely remove the worst performing families and retain only the best-ranked individuals from the better performing families. Following this treatment, it is managed for seed production. This PT-SSO strategy was recommended by (Harwood, et al., 2007) for six low-rainfall hardwood species in southern Australia.

Clonal seed orchards (CSOs) are established using progeny-tested individuals that have been cloned to increase their seed production potential. Cloning is usually achieved by grafting, which preserves the more mature physiological state of the scion and therefore promotes faster flowering in the orchard. Rooted cuttings or tissue culture propagation could also be used for cloning if necessary. The main advantages of a CSO above a SSO are greater genetic gain due to the more intensively selected orchard members, and faster flowering due to the physiologically mature nature of the scion. Disadvantages are greater establishment cost, poorer genetic diversity, and for some species, higher levels of mortality. CSOs are the orchard of choice for species with sure seed demand and more advanced genetic improvement programs, such as *E. globulus;* e.g. (Collins & Callister, 2010).

Development of a seed production strategy includes numerous other considerations, encompassing reproductive biology, genetic diversity, and management options. The first challenge facing many seed production facilities is a deficiency of flowers. The biology of flower initiation is not well understood for all tree species, and factors such as temperature, water relations, and soil attributes can all play a role. The flower initiation requirements for each particular species of interest must be researched as deeply as possible in the planning process. Flowering may be artificially stimulated by application of a hormone called paclobutrazol once the trees are fully established. Paclobutrazol acts to stunt vegetative growth and induce flowering sooner than would naturally occur. There are no known impacts of paclobutrazol on the germination or growth of seed. However, it should be applied in carefully measured amounts to the orchard and it persists for many years in the soil.

Flowering synchronicity is the second potential problem facing a seed orchard or production area. The within-season timing of flowering can be strongly inherited, leading to certain families or individuals that flower out of sync with unrelated trees. This situation causes inbreeding or self-pollination, which is expected to cause a reduction in the germination and growth potential of resultant seed (inbreeding depression). Seed production trees should be monitored carefully to record the flowering window of each one, and seed from trees that flower without unrelated synchronously flowering individuals can be removed or overlooked at harvest.

Outcrossing with unrelated individuals is also encouraged by a high degree of genetic diversity within the orchard. Genetic diversity can be quantified using known relationships amongst orchard members and/or DNA fingerprinting (genotyping). Reducing the number of relationships within the orchard is essential for avoiding inbreeding depression. Increasing the range of represented provenances contributes another level of genetic diversity to the produced seed, endowing the resultant stands with a wider range of genes that may be important for overcoming unforeseen biological and climatic challenges in the decades to come. Such considerations of genetic diversity are given when designing a rogueing scheme for conversion of a provenance trial to a SPA, or of a progeny trial to a SSO, and when identifying which clones to include in a CSO.

SPAs and orchards are generally pollinated by natural vectors such as insects and birds (open-pollination). Exceptions are the very large-fruited *E. globulus* which can be feasibly control-pollinated, and pines which can be artificially pollinated, and their progeny cloned for deployment. Leaving aside these special cases, it is important to encourage healthy populations of the pollinating fauna within the orchard. This may take special consideration if the orchard is located in an agricultural environment with heavy pesticide use, or which doesn't have a range of native vegetation to support diverse insect and bird communities. Genotyping and other DNA evaluation tools can be applied to determine the outcrossing rate of seed produced in such open-pollinated orchards and SPAs.

There are generally three methods for seed harvest: tree felling, working from an elevated work platform (EWP), and working from an orchard ladder. Tree felling is an efficient and low-cost method that may be preferred in more extensive and less-improved SPAs, where individual trees have abundant seed and lower values for future seed production. Seed harvest with an EWP is most common, although it does require some forward planning. In some jurisdictions the relevant safety regulations require a ground-based observer at all times. There are limits to the slope that EWPs can safely navigate, and the ground must be cleared of undergrowth and obstacles. Nevertheless, using the EWP means that the trees can grow taller and carry far more seed than if they must be pollarded to the height of an orchard ladder.

3.3 Seed production management options

The management of seed production can be structured in various ways. The simplest is for a tree planting organisation to produce its own seed based on internal forecast demand. While this option is appropriate for a relatively large industrial plantation company, it is not suitable for a diverse collection of individuals and organisations with smaller individual demand.

3.3.1 Form a seed production company

With sufficient capital, a seed production company may be formed and tasked with the mission of producing seed for a diverse customer base. A notable example of this structure in Australia is Seed Energy Pty Ltd, which was formed principally to produce genetically improved *P. radiata* and *E. globulus* seed from the Tree Breeding Australia (TBA) program for TBA members. Seed Energy has since expanded its operations to include *E. nitens, E. dunnii, E. saligna, E. smithii, E. cladocalyx, C. maculata*, and *C. citriodora* var *variegata.* It may be an option for a landholder who also owns genetic material rights to privately manage the seed production as a stand-alone business such as this.

3.3.2 Work with an existing seed production company

An alternative option for managing a trial-SPA or PT-SSO could be to make the resource available to an existing seed production company under agreeable terms, including compensation to the landowner. This presents the advantage of management by an entity experienced in seed production and with existing buyer networks and equipment. Buyers with planting operations in Victoria could potentially be given preference over those from interstate or overseas.

3.3.3 Form a collaborative venture

A third option is to form a collaborative venture amongst parties interested in planting the material in Victoria to manage the seed resource. In this case, the landowner would be appropriately compensated, and collaborative members would have far greater control over the seed resource and potentially access it at lower cost. The greatest obstacle to this model is shortage of capital and uncertainty about the value of the future seed resource amongst the potential collaborative members.

4. Seed availability

In order to determine the need for additional seed production areas, we conducted a survey of existing seed suppliers to understand what is currently available and at what level of improvement (if any). We contacted the suppliers listed in Table 1 and asked them to complete provide the following information for each of the 'promising species' (a list was provided).

- Species
- Provenance(s) - List or otherwise characterise the genetic base of the seed orchard/production area
- Level of genetic improvement:
  - - Unimproved/native
  - - Somewhat improved/1 gen
  - - Well improved/2 gen
- Type of orchard / seed production area:
  - - clonal seed orchard
  - - converted progeny trial
  - - converted provenance trial or pilot planting
- Genetic testing history - number and location of progeny trials informing genetic merit
- Seed in store:
  - quantity - estimated number of seed in store
  - cleaned? - has chaff has been removed
  - size - number of viables per kg, if known
- Production capacity - approximate sustained average yield per year
- Do future collections need to be pre-ordered?
  - only collect on demand
  - harvest regardless of prior demand
- Price - per seed, per viable, or per kg (specify cleaned or uncleaned)

Table 1 - seed suppliers contacted

Contact	Organisation
Graham Baldock	Kara Kara Seed Orchard
David Bush	CSIRO
Jo Lewis	Heartwood
Keith Cumming	Arborline
Barry Vaughan	Seed Energy
Paul Cotterill	Worrolong

Responses varied but enabled the following summary to be developed (Table 2).

Table 2 - Summary of seed supplier responses

Species	No. of suppliers	Level of improvement	Production capacity	Comments
Corymbia citriodora ssp variegata	3	1st Gen	Very High	
Corymbia maculata	3	1st Gen	Very High	Heaps available
Corymbia henryi	2	1st Gen	Moderate	Small amount available
Eucalyptus camaldulensis	2	1st Gen	Moderate	Demand has been low, so little seed on hand
Eucalyptus cladocalyx	4	1st & 2nd Gen	Very High	Well served for 1st Gen seed
Eucalyptus cypellocarpa	0	NA	None	
Eucalyptus globulus ssp. bicostata	0	NA	None	
Eucalyptus grandis	2	1st Gen	Moderate	Demand is low
Eucalyptus leucoxylon	1	Best Prov.s	Low	
Eucalyptus melliodora	2	1st Gen	Moderate	Demand has been low, so no seed on hand
Eucalyptus muelleriana	2	1st Gen	Moderate	Small amount available

Species	No. of suppliers	Level of improvement	Production capacity	Comments
Eucalyptus occidentalis	3	1st Gen	High	Heaps available, demand is low
Eucalyptus saligna	3	1st Gen	High	Small amount available, demand is low
Eucalyptus sideroxylon	3	1st Gen	Low	Late flowering. Demand exceeds supply
Eucalyptus tereticornis	0	NA	None	
Eucalyptus tricarpa	2	1st Gen	Low	Late flowering. Demand exceeds supply
Pinus pinaster	0	NA	None	

In addition to this information, David Bush (CSIRO) provided some useful insights in respect of seed availability and genetic improvement. He highlighted that there is plenty of seed available for some of the most promising species (*C. maculata, E. cladocalyx, E. occidentalis*) The conversion of existing plantations of such species to seed production areas would not be of benefit for the landowner.

> *If we received market signals by way of demand for many of the species you have listed we could significantly increase production. We have invested heavily in the genetic improvement of several of these species.*

References

Collins, S. L. & Callister, A. N., 2010. Genetic and environmental influences on capsule retention following controlled pollination of Eucalyptus globulus flowers.. *Australain Forestry Journal,* pp. 73 (3):198-203.

Cotterill, P. P. & Dean, C. A., 1990. *Successful Tree Breeding with Index Selection.,* s.l.: Melbourne: CSIRO..

Cotterill, P. P. et al., 2001. *Compendium of Hardwood Breeding Strategies,* s.l.: Australian Low Rainfall Tree Improvement Group, No. 01/100. Project No. CSF-58A, pp. 140 pp. RIRDC.

DigitalGlobe, 2023. *ImageConnect,* s.l.: s.n.

Grundy, M. et al., 2015. Soil and landcape grid of Australia. *Soil Research 53.,* pp. (8): 835-844.

Harwood, C. E. et al., 2007. Achievements in forest tree genetic improvement in Australia and New Zealand. 4. Tree improvement for low-rainfall farm forestry.. *Australian Forestry Journal,* pp. 70:23-27..

Jeffery, S. J., Carter, J. O., Moodie, K. M. & Beswick, A. R., 2001. Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environ Model Softw 16.,* pp. (4):309-330.

Keenan, R. J., Ryan, Z. & Stewart, H., 2020. *Climate Change and Carbon Policy Assessment Report,* Melbourne: School of Ecosystem and Forest Sciences, Faculty of Science, University of Melbourne.

Landsberg, J. & Waring, R., 1997. A generalised model of forest producivity using simplidied concepts of radiation-use efficiency, carbon balance and partitioning. *For Ecol Man 95,* pp. (3): 209-228.

Landsberg, J., Waring, R. & Coops, N., 2003. Performance of the forest productivity model 3-PG applied to a wide range of forest types. *For Ecol Man,* pp. 172 (2-3):199-214..

Landsberg, J., Waring, R. & Coops, N., 2003. Performance of the forest productivity model 3-PG applied to a wide range of forest types. *For Ecol Man 172.,* pp. (2-3): 199-214.

Paul, K. I., Booth, T. H., Jovanovic, T. S. & Morris, P. J., 2007. Calibration of the forest growth model 3-PG to eucalypt plantations growing in low rainfall regions of Australia. *For Ecol Man 243,* pp. (2-3): 237-247.

Stackpole, D. & Dore, D., 2020. *Re-measurement of lower-rainfall farm forestry species in Victoria to improve genetic quality and establishment: A report on Establishment Techniques, Sawlog Species Comparison and Eucalyptus cladocalyx Progeny Trials in south-west Victoria after eighteen,* s.l.: Forest and Wood Products Austalia Project: VNC494-1920.

Trotsiuk, V. et al., 2022. *Package 'r3PG',* s.l.: s.n.

White, T. L., Adams, W. T. & Neale, D. B., 2007. *Forest Genetics.* s.l.:Oxfordshire, UK: CABI Publishing.

Zobel, B. & Talbert, J., 1984. *Applied Forest Tree Improvement.* s.l.:John Wiley & Sons.