TRIG FINAL REPORT

Trials Review, Information and Genetics Project

Forestry Australia

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Disclaimer

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Executive summary

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) and Forestry Australia. 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.

PF Olsen Australia undertook the project over 14 months and delivered the following outcomes:

1. The farm forestry trial database was updated with new trials and information gathered during various stages of the project. Priority sites were identified, inventory conducted, and works completed. Productivity maps of two key species (*Eucalyptus cladocalyx* and *Corymbia maculata*) across Victoria were developed using the data from the inventory.
2. A number of model plantings were identified which, with the agreement of the landowners, can be used as demonstration sites. These sites have had signage installed to aid with interpretation.
3. The availability of seed for the shortlist of promising seed was explored. It was discovered that there is generally a plentiful supply of seed and that sufficient orchards already exist.
4. As well as this report, a webpage has been created that includes case studies and an interactive map that helps identify species for farm forestry. The potential for accessing carbon markets in Australia was described.

1. 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. Data received

PF Olsen received a Microsoft Access database from DJPR that contained a collection of information relating to plantation trials in Victoria. These plantation trials were originally established for a range of purposes and from a variety of funding sources. The funding sources and trial summary information are provided in Table 1.

Table 1 - Database summary statistics

Funding source	Trial type(s)	# of trials	# of species	Establishment year(s)
Australian Centre for International Agricultural Research	Species	2	17	1994
Australian Low Rainfall Tree Improvement Group	Genetic gain, Progeny, Genetics	24	10	2000 to 2003
Corangamite Farm Forestry Project	Provenance, Species	7	26	1994 to 1996
CSIRO	Provenance	3	5	1998
DCNR Timber Industry Strategy	Species	1	5	1989
Ensis (CSIRO/FRNZ) trial	Progeny, Hybrids	3	3	1998 to 2005
Florasearch JVAP Biomass trials	Species	1	1	2004
Glenelg Region Integrated Farm Forestry	Spacing, Species, Permanent Sample Plot, Provenance	171	34	1993 to 1998
Heartlands, CSIRO	Species	2	14	2002
National Afforestation Project	Salinity	40	86	1988 to 1991
North East Farm Forestry Program	Species	4	32	1985 to 1996
Plantations for Carbon	Provenance	1	1	2007
Victoria's 150th Anniversary	Species	14	74	1981 to 1985
Woodside - Sawlogs for Salinity	Species, Spacing, Salinity	1	3	2006
Private Forestry Development Committee	Species	7	32	1999
NA/unknown	Species, Spacing, Provenance, Progeny, Genetics, Permanent Sample Plot, Clones, Hybrids, Salinity, Site Prep & Fertiliser, Arboretum	94	132	1968 to 2014

The information in the database varies depending on the project and the level of recording at the establishment phase. Information available includes:

- Site details
- Landowner details (out of date in many instances)
- Trial design details
- Location (latitude and longitude, with variable accuracy)
- Species (and provenance in some cases)
- Spacing
- Date of establishment
- Works (e.g., planting, spraying, site inspections, inventory)
- References to documents and publications relating to the plantations and trials.

Although some inventory events were recorded in the database, the associated inventory data was not incorporated. It is believed that paper-based inventory data (and other information) may be available, but we had variable success in tracking down such records.

In addition to reviewing the database, we reached out through the Forestry Australia membership and contact network in an attempt to discover additional plantations. This process led to the addition of 29 more sites (which have been included in the statistics of Table 1).

3. Initial analysis

3.1 Initial desktop analysis

A process of site location validation was conducted by importing the latitude and longitude data into a Geographic Information System (GIS). These point locations were then viewed with the most current satellite imagery available (DigitalGlobe, 2023) to determine if there was a plantation at each point. In instances where the point didn't match with a stand of trees, a nearby search was carried out in case the original location data was slightly incorrect. If a stand of trees was located nearby, the lat/long data would be adjusted to be centred on the identified stand.

At the end of this process, 318 sites had confirmed plantations and 28 sites could not be spatially located (i.e. the plantation had been cleared, or the point location was significantly out).

3.2 Historical trial project themes

To assist in the management and analysis of the historical data, we categorised each of the trials into themes. Figure 1 presents a histogram of the number of sites by theme.

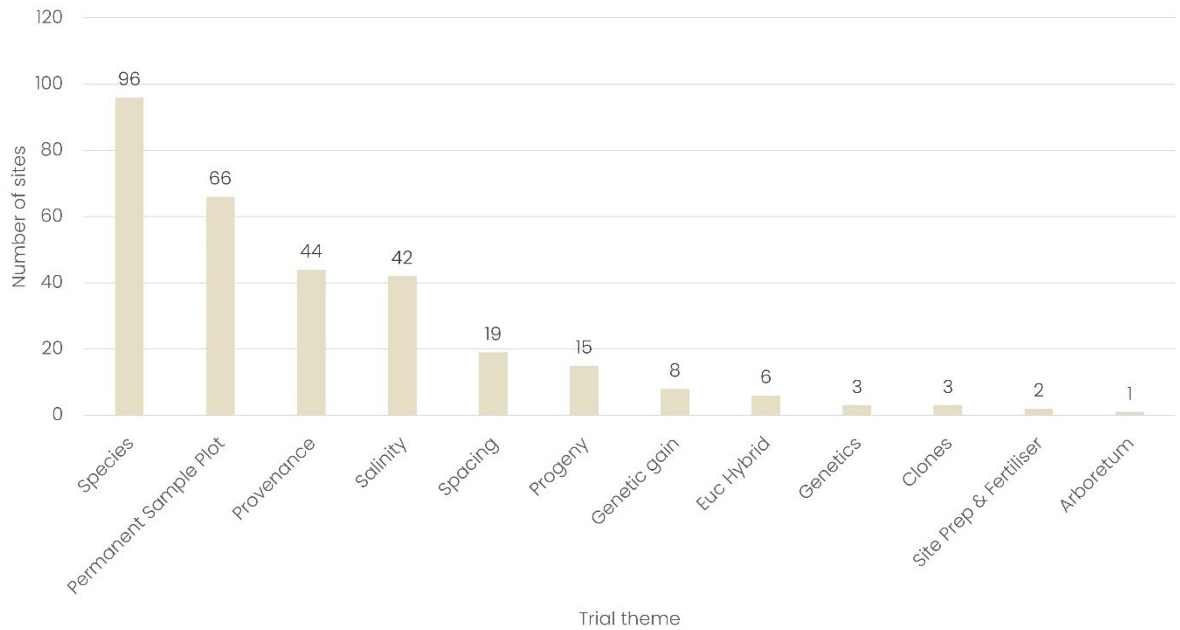


Figure 1- Number of sites by theme

3.3 Most promising species

After the initial data analysis we discovered that:

- 216 individual species were listed as being planted at least once on at least one site.
- 91 species were only represented once.
- 33 species were represented at least twice.

Through the desktop analysis, discussions with some members of the TRIG Steering Committee (Philippa Noble, Andrew Lang and Andrew Walpole) and survey of Forestry Australia members, the following list of 'promising species was developed:

- *Corymbia maculata*- Spotted gum
- *Eucalyptus camaldulensis*- River red gum
- *Eucalyptus cladocalyx*- Sugar gum
- *Eucalyptus occidentalis*- Swamp yate
- *Eucalyptus saligna*- Sydney blue gum
- *Eucalyptus grandis*- Flooded gum
- *Eucalyptus sideroxylon*- Red ironbark

- *Eucalyptus melliodora*– Yellow box
- *Eucalyptus cypellocarpa*- Mountain grey gum
- *Eucalyptus tricarpa*- Red ironbark
- *Eucalyptus leucoxylon*- Yellow gum
- *Corymbia citriodora ssp variegata*- Lemon-scented gum
- *Eucalyptus tereticornis*- Forest red gum
- *Pinus pinaster*- Maritime pine
- *Corymbia henryi*- Large-leaved spotted gum
- *Eucalyptus globulus ssp bicostata*- Southern blue gum

3.4 Exclusion of salinity sites

During the process of aerial image analysis, it was determined that, of the 24 Salinity trial sites, 14 were deemed to be 'patchy' at best (Figure 2).

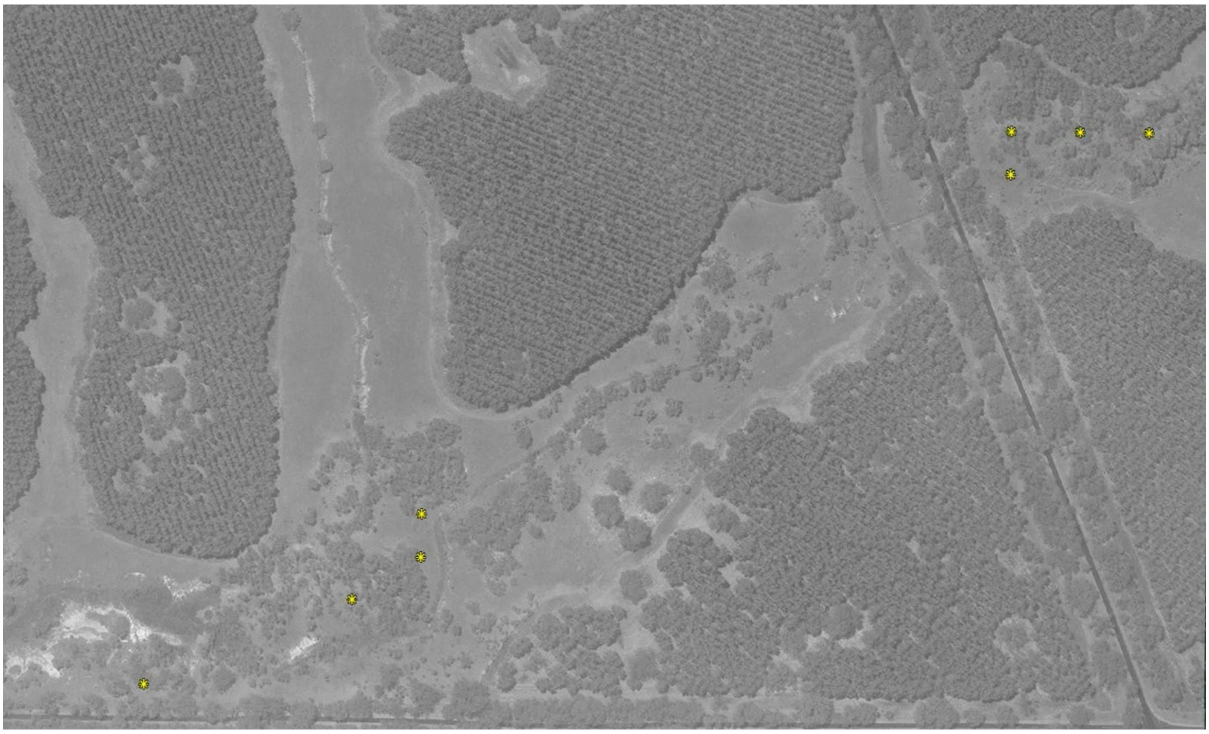


Figure 2- Salinity site example (yellow dots in the image are salinity trial sites showing highly variable tree cover)

Salinity trials are specifically planted on sites with salinity issues, with the aim of ameliorating this issue. Measuring trees on such sites may not provide useful information for future farm forestry plantings with a focus on commercial outcomes. With this in mind, none of the salinity sites were selected for site inspection.

We understand that Glenn Dale (Managing Director and Chief Technical Officer of Verterra, previously called Tree Crop Technologies) was involved with the planting of salinity trials in Victoria. Glen provided the following information on these trials.

> *There were 49 trials planted around Victoria, many were very small. Of the 1,000 odd clones, there were about five to eight that performed very well across a wide range of site conditions, and one in particular that was good everywhere.*

4. Site inspections

Only sites that had at least one of the 'promising' species (listed previously) were selected for site inspection.

For all the sites that had a validated spatial location, attempts were made to contact the landowners and seek their approval for a site inspection. We attempted to contact the owners of 83 sites and were successful in gaining approval to conduct inspections on 42 sites.

Using the most recent satellite imagery, the boundaries of the trials on these 42 sites was digitised.

Site inspections were conducted by PF Olsen staff across the sites where landowner approval had been granted (Figure 3). PF Olsen developed an electronic form that was used by its forestry team when they were on site. The electronic form was developed within the ESRI ArcGIS application 'Collector'. The complete form used for the site inspections is provided in Appendix A.

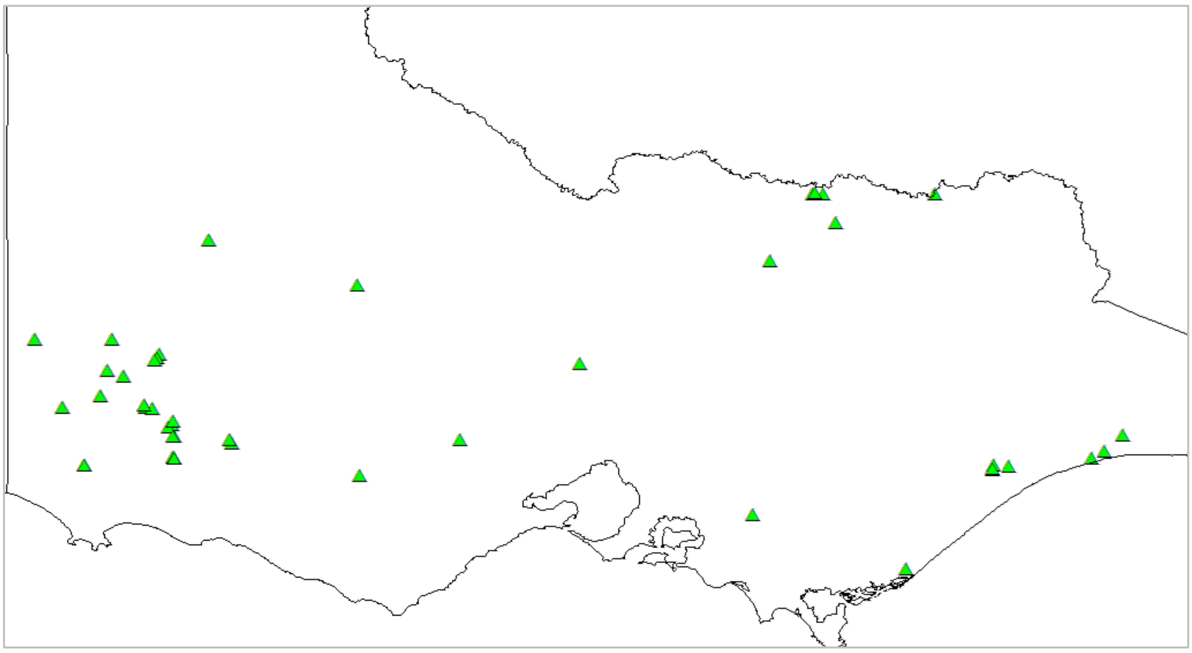


Figure 3- Distribution of inspected sites

The inspection form included general questions about the site, identification of hazards and suggestions for potential future uses. The application also allowed our team to:

- Adjust the spatial location of the stands when the database location was not accurate.
- Determine the most appropriate inventory type for the subsequent inventory.

5. Inventory sites

Following the site inspections, 19 sites were determined to be suitable for an inventory (Figure 4). These sites had to meet the following criteria:

- stands in good health
- low levels of disease or insect damage
- potential future demonstration site or potential future improved seed area
- safe and accessible site for contractor
- owner's permission obtained.

The inventory program was completed during December 2022 and January 2023. Any site that also had trials of other species was also included in the inventory program. Although the data has been added to the database, only information about the promising species is presented in this report. Of the 16 promising species, 13 were inventoried. The trials that contained the other three species (*C. henryi, E. cypellocarpa, P. pinaster)* did not meet the above criteria.

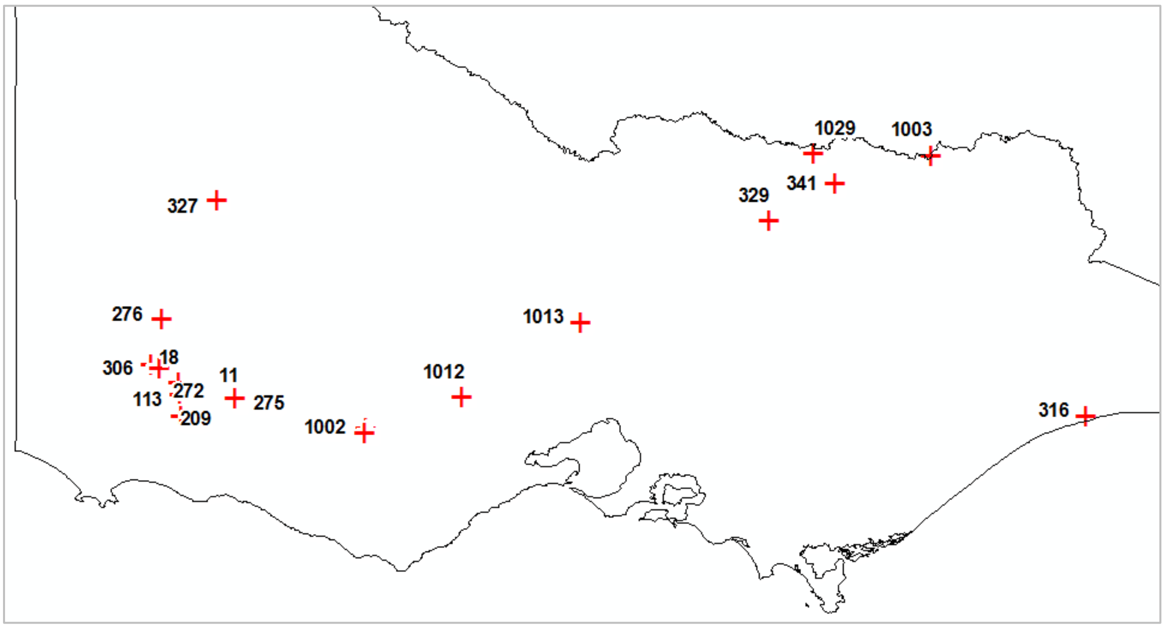


Figure 4- Distribution of inventory sites across the state with Site ID as labelss

The inventory data was used to inform the development of individual management plans for each site. For full details on the contents of the management plans see Section 7.1.

5.1 Inventory design

The inventory was intended to be rapid to enable the capture of indicative information across a wide range of sites. A general sampling intensity of 1 plot for every 4 hectares was applied. At least one plot per trial site was established. For stands that showed a visual variation, additional inventory plots were established to capture the variation. In most cases, due to the generally small area of each stand, there were few plots per species. Circular plots were randomly located within the mapped area of the stand and the following metrics captured using PlotSafe:

Plot level:

- Plot size 0.4 ha
- Plot location (latitude and longitude)
- Slope
- Aspect
- Species

Tree level:

- Tree status (live, dead, runt, thinned)
- Diameter (in cm over bark at breast height (1.3 m))
- Height (in meters for 5 trees representing, 3 largest diameter, 1 average diameter and 1 smallest diameter).
  - Height of all other trees was predicted from regression modelling the measured heights and diameters of each plot.
- Tree health (overall crown assessment and check of stem)
  - Pest
  - Disease
  - Other damage
- Branching:
  - No branches
  - Branches <=4cm
  - Branches <=7cm
  - Branches <=10cm
- Sweep (a measure of how far the stem deviates from straight):
  - No deviation
  - Minimal deviation
  - Extreme deviation
- Forking y/n within commercial stem

5.2 Summary of inventory results

The inventory data was analysed using YTGen software. The summary data provides an opportunity to explore some standard forestry metrics to enable comparison across species. As noted previously, plot numbers for most species are low, so the results presented should be considered as indicative rather than absolute. Comparisons also need to take into account the range of stand ages (from 12 to 55 years).

Table 2- Inventory sites and summary data

Age	Site ID	Species	Area (ha)	Number of plots	Ave stocking (stems/ha)	Ave BA (m2/ha)	Ave top height (m)	Ave volume (m3/ha)	Ave MAI (m3/ha/yr)
12	1013	Eucalyptus saligna	1.6	1	675	18	15	68	5
15	1012	Eucalyptus cladocalyx	2.2	24	494	16	17	69	4
15	1002	Eucalyptus globulus ssp bicostata	3.8	1	250	8	21	44	3
15	1002	Corymbia maculata	0.5	1	133	4	13	15	1
15	1002	Eucalyptus cladocalyx	1.3	2	225	8	16	32	2
15	1002	Eucalyptus occidentalis	1.0	1	975	24	19	116	8
15	1002	Eucalyptus melliodora	0.7	1	650	36	17	153	10
18	1003	Eucalyptus cladocalyx	6.2	1	317	11	19	51	3
18	1003	Corymbia maculata	5.5	2	417	20	22	119	6
19	309	Corymbia citriodora ssp variegata	11.6	3	328	20	19	104	5
20	1013	Eucalyptus tricarpa	0.9	2	488	16	14	52	3
20	1013	Corymbia maculata	85.7	4	375	17	14	67	3
20	1013	Eucalyptus obliqua	3.5	2	525	42	17	190	9
20	306	Eucalyptus sideroxylon	6.5	2	508	15	17	62	3

Age	Site ID	Species	Area (ha)	Number of plots	Ave stocking (stems/ha)	Ave BA (m2/ha)	Ave top height (m)	Ave volume (m3/ha)	Ave MAI (m3/ha/yr)
21	276	Corymbia maculata	17.2	10	745	18	15	66	3
21	209	Corymbia maculata	2.5	1	525	26	21	145	7
21	275	Eucalyptus occidentalis	7.8	2	575	22	19	106	5
22	272	Corymbia maculata	0.7	1	283	23	22	134	6
22	273	Eucalyptus cladocalyx	1.7	1	233	20	22	125	6
22	316	Corymbia maculata	3.6	1	400	18	19	85	4
22	316	Eucalyptus tricarpa	2.0	1	283	19	19	95	4
22	316	Eucalyptus tereticornis	2.4	3	608	24	19	112	5
22	341	Eucalyptus camaldulensis hybrids	34.7	6	396	17	18	82	4
24	329	Eucalyptus cladocalyx	3.5	1	625	21	26	134	5
26	1029	Eucalyptus sideroxylon	3.4	1	450	12	16	49	2
27	113	Corymbia maculata	2.2	3	289	30	21	186	7
29	11	Eucalyptus grandis	2.4	3	283	19	22	116	4
37	18	Eucalyptus leucoxylon	4.0	3	200	15	16	70	2
54	327	Eucalyptus occidentalis	3.0	3	194	13	20	68	1
54	327	Eucalyptus cladocalyx	91.0	21	515	14	19	63	1

The small size of many of the stands for many species limited the number of plots that could be established. This limitation reduced the efficacy of the inventory data for analysis. Figure 5 displays the distribution of plots by species across all sites. Three species had only one plot each.

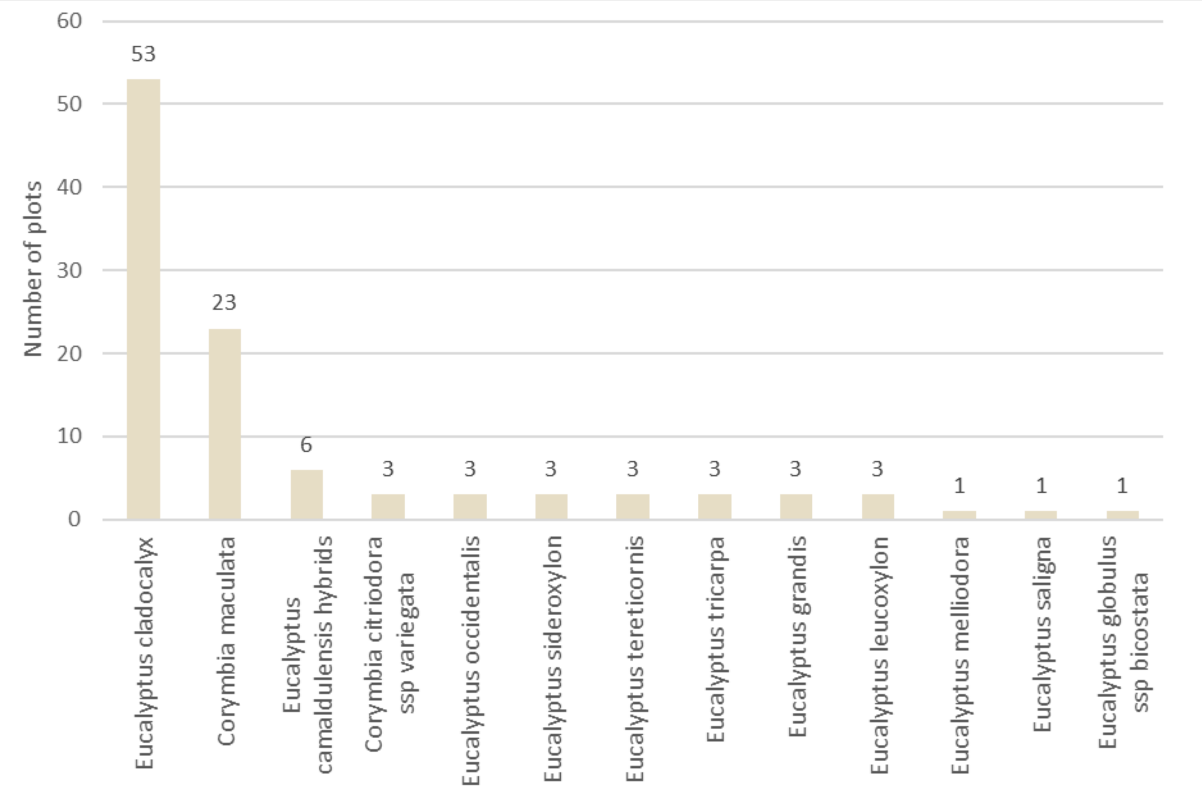


Figure 5- Number of plots by species across all sites

6. Productivity mapping

6.1 Background

Of the 16 priority species considered in the project, only *Eucalyptus cladocalyx* and *Corymbia maculata* were represented by enough inventory plots to consider modelling growth as a function of age and environmental variables.

E. cladocalyx was measured in 50 plots at 5 site-age combinations, while *C. maculata* was measured in 23 plots at 6 site-age combinations (Table 2).

The unbalanced distribution of plots with age and site combined with great variation in previous management (e.g. stocking ranged from 133 sph to 1325 sph) would have prevented a multiple regression model from providing results we could be confident in. Fortunately, the 3PG (use of Physiological Principles in Predicting Growth) process-based model has been parameterised for these two species, providing a framework for model prediction at unobserved sites and with a standard silviculture.

3PG is a simpler process-based stand growth model than alternatives such as CABALA or APSIM and operates at monthly time steps (Landsberg & Waring, 1997). It has been found to produce realistic predictions in a wide range of species and situations (Landsberg et al. 2003). For example, within the R Software environment, the function ***i_parameters_lit*** from package r3PG (Trotsiuk, et al., 2022) lists 110 different parameterisations for 3PG across even and uneven-aged stands for 51 species. 3PG is the model that underpins forest productivity predictions in FullCAM. Parameterisations of 3PG for *E. cladocalyx* and *C. maculata* were published by (Paul, et al., 2007) using data from 55 *E. cladocalyx* stands and 37 *C. maculata* stands across south-eastern Australia.

The objectives of this part of the TRIG project were to:

1. determine fine-tuning parameters for 3PG to obtain the best accordance between observed mean DBH and mean HT and 3PG-predicted values in each TRIG plot of *E. cladocalyx* and *C. maculata*, and
2. apply the tuned 3PG model to a typical farm forestry silviculture regime at gridded points across the agricultural landscape of Victoria with mean annual rainfall greater than 400 mm, to determine productivity zones for these species.

6.2 Materials and methods

6.2.1 Growth and site data

Individual-tree diameter at breast height (DBH) and a sample of tree heights (HT) were recorded in each plot during the TRIG inventory (refer to Section 5.1 for details). The current plot stocking and age were also recorded. The thinning history of each stand was unknown and site-specific soils data were unavailable.

Soils data were obtained from the Soils and Landscape Grid of Australia (SGLA) (Grundy, et al., 2015) which provided estimates of a required 3PG input maximum soil available water (*awc_max*), in the upper 2 metres. The other 3PG site input related to soils was a fertility rating from 0 to 1, which was indicated in a very general sense from the SLGA data.

Daily weather data were downloaded from the SILO database (Jeffery, et al., 2001) at each TRIG site location from June 1 in the respective year of planting until December 1 2022. Using, MS Excel, these data were used to calculate the mean monthly inputs required for 3PG:

- Mean daily maximum temperature (*tmp_max*),
- Mean daily minimum temperature (*tmp_min*),
- Mean daily mean temperature (*tmp_ave*),
- Sum of rainfall (*prcp*),
- Mean daily solar radiation (*srad*), and
- Number of frost days (*frost_days*)

Mean DBH and HT were also obtained from a recent report of *E. cladocalyx* and *C. maculata* growth near Lismore in Victoria (Stackpole & Dore, 2020).

6.2.2 Analysis of height-diameter relationships

The 3PG model calculates net primary productivity at the stand scale, then distributes it amongst roots, stem, and leaves. Mean DBH is calculated as a model output using a function of stem biomass and stocking. 3PG doesn't produce a direct output of tree height and the (Paul, et al., 2007) paper did not include the DBH-HT relationship in its scope. Therefore, a preliminary step was to produce basic height functions from the TRIG inventory data that could be used for deriving HT predictions from the 3PG DBH predictions.

Few model forms were compared, as this was not a central project objective. The allometric model form *ln(HT) ~ ln(a) + b.ln(DBH)* proved adequate for both species and the influence of age and stocking on coefficients *a* and *b* was explored. The R function *nls()* from the *stats* package was used.

6.2.3 Fine-tuning the 3PG model

The 3PG model was implemented in R using the *r3PG* package (Trotsiuk, et al., 2022) with parameterisations published in (Paul, et al., 2007)

A thinning record was constructed for each plot based on the final stocking observed in 2022. For example, if a 20+ year-old plot was observed at less than 300 sph, it was assumed that it had been subjected to 2 thinning events. If it was observed at more than 500 sph, it was assumed that a single thinning had been conducted. Although a mortality function is available in 3PG, stocking control was undertaken only by specified thinning to avoid over-fitting in the absence of longitudinal data.

The only site-specific tuning parameter built into 3PG is the *fertility* index (0-1). However, *awc_max* is effectively unknown at most sites and can therefore be considered a second option for model fine-tuning.

The fine-tuning process was conducted at the site level, and so it affected multiple predictions similarly within each site that had multiple plots. At first, *fertility* was set at 0.5 and *awc_max* was set at the estimated total in the top 2 m from SLGA data at each site. These two parameters were then iteratively adjusted upward or downward until the predicted mean DBH best matched the observed mean DBH. Tuning parameters were compared amongst sites to determine the optimum setting for predictions across the state.

6.2.4 Mapping zones of productivity

Prediction points were placed at a 0.1 degree interval across the larger expanses of agricultural lands in Victoria with a mean annual rainfall greater than approximately 400 mm. This resulted in 1251 points in total (Figure 6).

Daily weather data were obtained from SILO at each point from January 1, 2002 to December 31, 2021. *tmp_max, tmp_min, tmp_ave, prcp, srad,* and *frost_days* were calculated for each month, as described above. 20-year average values for each month were then calculated from the month-in-year values, and replicated 25 times to create a set of average climate values specific to each prediction point.

3PG was run for both species at each prediction point using the best tuning values identified in the previous step, the point-specific average climate, and assuming planting density at 800 sph, thinning to 500 sph at 5 years, and to 200 sph at 12 years. The 25-year mean DBH and mean HT were output for each prediction point.

A file of predicted mean DBH and HT values with associated coordinates was introduced to the QGIS mapping platform (version 3.22.12-Białowieża) and polygons were created around four classes of productivity for each species:

- 'moderate' where mean DBH is between 25-30 cm,
- 'good' where mean DBH is between 30-35 cm,
- 'very good' where mean DBH is between 35-40 cm, and
- 'excellent' where mean DBH is greater than 40 cm.

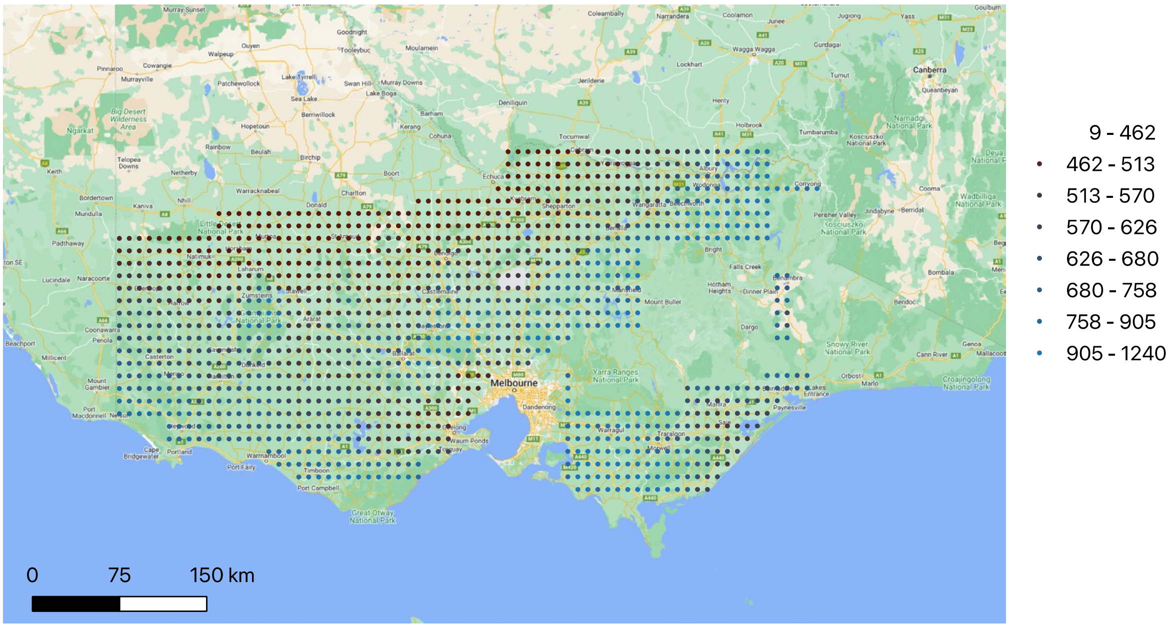


Figure 6-Location of 1251 prediction points across Victoria, with colour scale indicating mean annual rainfall from 2002 to 2022

6.3 Results and discussion

6.3.1 Height-diameter relationships

The *E. cladocalyx* data supported a complex interpretation of the DBH-HT relationship with linear and 2nd-order polynomial effects of age on the intercept and slope and effects of stocking on the slope:

$$ln(H) = ln\left(a_0 + a_1 A + \frac{a_2 A^2}{100}\right) + \left(b_1 A + \frac{b_2 A^2}{100} + b_3 S\right) ln(D)$$

where *H* is a vector of tree heights with associated values of age in years (A), stocking in sph (S), and DBH (D). All six model coefficients were highly significant, as follows:

	Estimate	Std. Error	t value	Pr(>|t|)	
a0	6.564e+00	2.065e-01	31.79	< 2e-16	***
a1	-2.279e-01	1.087e-02	-20.96	< 2e-16	***
a2	2.629e-01	1.650e-02	15.93	< 2e-16	***
b1	3.514e-02	1.176e-03	29.89	< 2e-16	***
b2	-4.110e-02	2.197e-03	-18.71	< 2e-16	***
b3	6.907e-05	1.357e-05	5.09	4.29e-07	***

The predicted-observed height relationship for *E. cladocalyx* is shown in Figure 7 graph A.

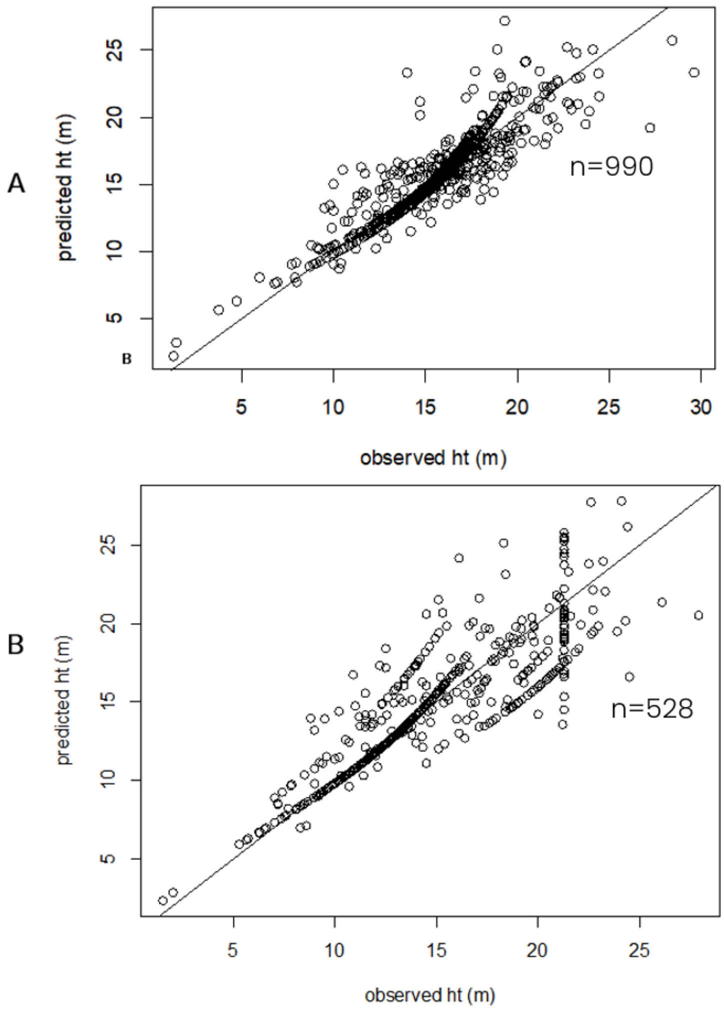


Figure 7- Relationship between observed and predicted tree height in (A) E. cladocalyx (n=990) and (B) C. maculata (n=528)

The *C. maculata* data did not support such a complicated prediction model and it broke down when anything more complicated than the simplest model form was attempted:

$$\ln(H) = ln(a_0) + (b_0)\ln(D)$$

Coefficient estimates are:

	Estimate	Std. Error	t value	Pr(>|t|)	
a0	1.77580	0.07214	24.62	<2e-16	***
b0	0.69450	0.01356	51.20	<2e-16	***

The predicted-observed height relationship is for *C. maculata* shown in Figure 7 graph B. There is an undesirable amount of scatter around this relationship, suggesting that it fails to perform well under all circumstances. A larger and better structured dataset would be required to undertake an improvement.

6.3.2 Fine-tuning the 3PG model

The 3PG model generally matched observed mean DBH best with the *fertility* parameter at 1 and the *awc_max* parameter set at 200 mm (Table 3, Figure 8).

Note that SLGA estimates for *awc_max* ranged from 67 to 99 (mean 84) mm for the top 2 m, depending on texture.

Table 3- Best fine-tuning parameters 'fertility' and maximum available water content 'awc_max' at each combination of site and species

Site	General Location	Age	MAR (mm)	Fertility	awc_max
Eucalyptus cladocalyx					
273	Hamilton	22	675	1	200
327	Horsham	55	395	0.1	100
329	Benalla	25	581	1	200
1002	Lismore	16	632	1	200
1003	Wodonga	19	736	0.5	200
1012	Lal Lal	16	732	1	200
Wallinduc[1]	Lismore	16	550	1	200

Site	General Location	Age	MAR (mm)	Fertility	awc_max
Corymbia maculata					
113	Hamilton	28	600	1	200
209	Hamilton	22	600	1	200
272	Hamilton	22	675	1	200
276	W. VIC	22	550	1	200
316	Lake Tyres	23	700	0.15	100
1002	Lismore	16	630	0.2	100
1003	Wodonga	19	730	1	200
1013	Central VIC	21	520	1	200
Wallinduc[1]	Lismore	16	550	1	200

[1] Wallinduc is the site name from the (Stackpole & Dore, 2020) report.

The 21 plots from Site 327 (low-rainfall, 55-year-old stands) were significant outliers on the predicted-observed plots for *E. cladocalyx* (triangle symbols in Figure 8 graphs A and B). The 3 points significantly below the 1:1 line in Figure 8 graph A are from Wallinduc (Stackpole & Dore, 2020), where the very highly stocked *E. cladocalyx* grew significantly better than expected from the 3PG predictions.

The HT predictions for *E. cladocalyx* with observed mean HT between 13 and 17 m were clustered around 15 m (Figure 8 graph B). This suggests that the DBH-HT model was insensitive to this order of variation, although this is not a material concern for the scope of modelling in this exercise.

The predicted-observed relationships for *C. maculata* were distributed more evenly across a wide range of DBH and HT, with points scattered reasonably well around the 1:1 line (Figure 8 graphs C and D). This suggests that the 3PG prediction using *fertiliser=1* and *awc_max*=200 m performs adequately for the species, despite the optimum settings for sites 316 and 1002 being different (Table 3).

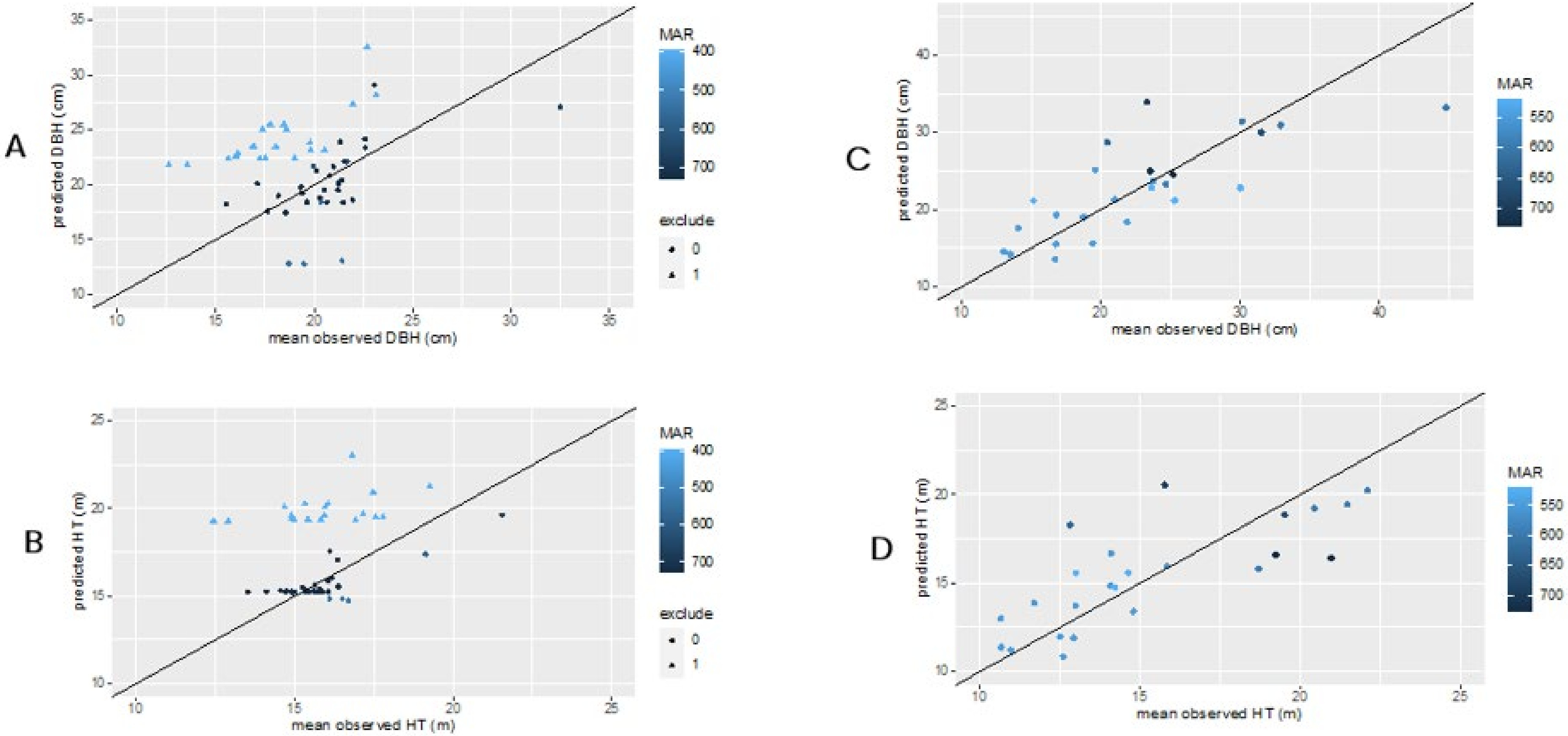


Figure 8- 3PG-predicted versus observed mean (A,C) DBH and (B,D) height for (A,B) E. cladocalyx and (C,D) C. maculata with outlying site 327 identified by triangles. Model settings were fertility=1 and awc_max=200 mm

Plots similar to those in Figure 8 were created with stocking as a continuous scale variable but they did not reveal any trend in model accuracy with stocking.

An example of 3PG model input (assumed stocking) and outputs (DBH and HT) is presented in Figure 9 Similar plots were examined during the model-fitting process for all plots and sites.

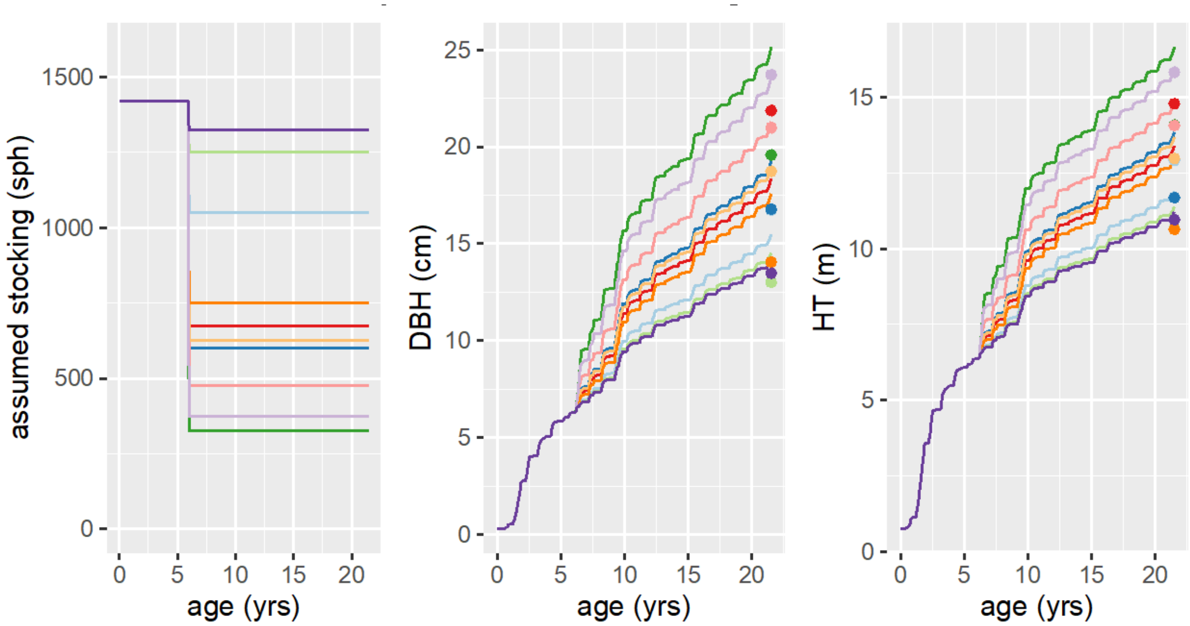


Figure 9- 3PG model predictions for C. maculata in 10 plots at Site 276

6.3.3 Mapping zones of productivity

Maps of productivity zones for *E. cladocalyx* and *C. maculata* are presented in Figures 5 and 6. The only mapped area that qualified as 'excellent' productivity (DBH>40 cm in 25 years) for *E. cladocalyx* occurred in western Gippsland (Figure 10), where the drought-hardy species will be less productive than other alternatives including *C. maculata*. In contrast, the 'excellent' productivity class for *C. maculata* extended along the coast in the western half of the state and along the foothills of the Great Dividing Range (Figure 11). The predicted mean DBH of *C. maculata* exceeded in 50 cm in some parts of western Gippsland.

Although *E. cladocalyx* has a well-deserved reputation for drought-hardiness, the distribution of the 'moderate' productivity zone (DBH from 25-30 cm in 25 years) extended further north for *C. maculata* (Figure 10 & Figure 11). In other respects, the patterns of productivity zonation were similar between the two species, although at a given location the productivity zone for *C. maculata* tended to be one class above that for *E. cladocalyx*.

The mapping presented here could be replicated for other species with 3PG parameterisations such as *E. globulus* and *Pinus radiata*. However, 3PG parameterisations are currently unavailable for the remaining species targeted in the TRIG project. The process of 3PG parameterisation involves measuring stands across a wide range of environmental conditions and ages. For example, Paul *et al* (2007) measured *E. cladocalyx* at 55 sites and *E. maculata* at 37 sites. It also requires a detailed measurement of perhaps a dozen destructively harvested trees on multiple sites, including excavation of roots to 2 mm thickness. This future work is highly recommended for alternative species that can be identified with commercially viable prospects for timber and carbon.

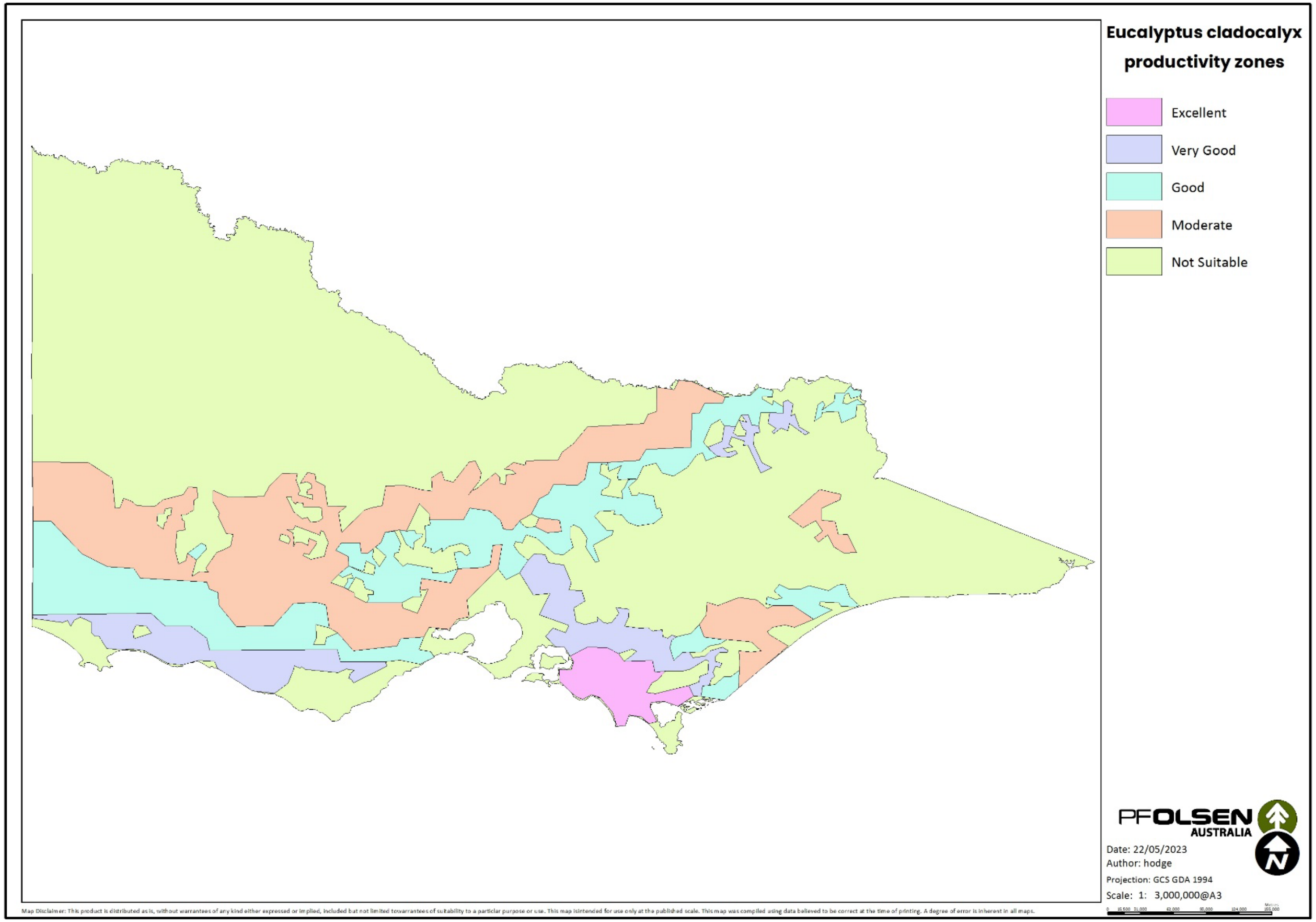


Figure 10- Map of Eucalyptus cladocalyx productivity zones in Victoria based on 3PG modelling at 1251 prediction points: 'moderate' for mean DBH between 25 and 30 cm, 'good' for mean DBH between 30 and 35 cm, 'very Good' for mean DBH between 35 and 40 cm, and 'excellent' for mean DBH greater than 40 cm

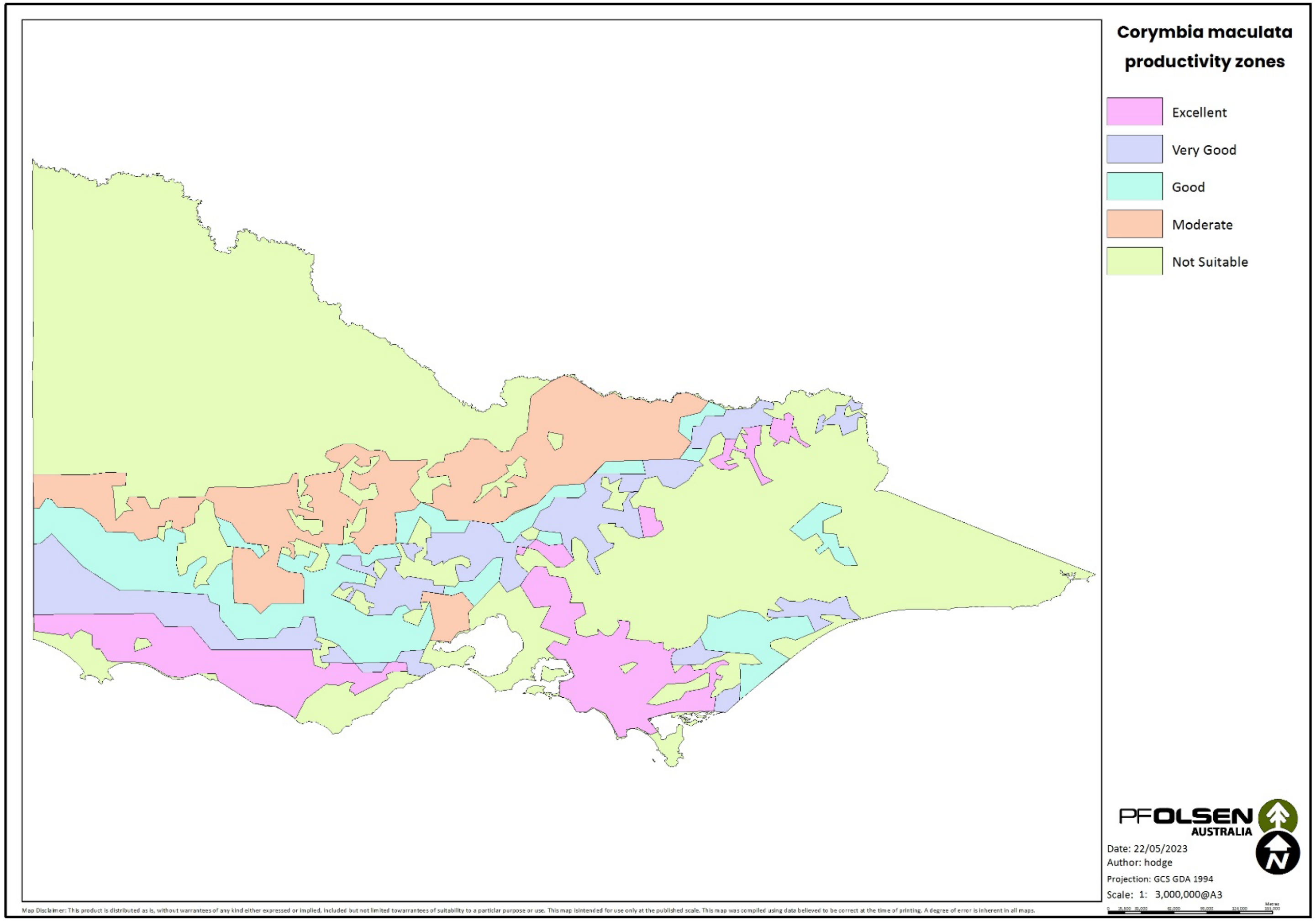


Figure 11-Map of Corymbia maculata productivity zones in Victoria based on 3PG modelling at 1251 prediction points: 'moderate' for mean DBH between 25 and 30 cm, 'good' for mean DBH between 30 and 35 cm, 'veryGood' for mean DBH between 35 and 40 cm, and excellent for mean DBH greater than 40 cm

7. Works

After the completion of the inventory program, each trial's results were analysed and summarised into a management plan.

7.1 Management plans

These managements plans followed the following structure:

- Site details
- Species information
- Inventory outputs:
  - Average basal area (m^3 per ha)
  - Average stem volume (m^3 per ha)
  - Average stocking (stems per ha)
  - Average MAI (m^3 per ha)
  - Plot map
  - Stem diameter distribution across the stand
- Site description
- Recommended works
- Site map
- Photos (where available).

7.2 Recommended works

In the process of developing the Management Plans, some works were identified that will assist with future demonstration sites. These works were endorsed by the TRIG Project Steering Committee and are described in the following sections.

7.3 Thinning

Three properties were identified as good candidates for thinning (Table 4). Sites 275 and 316 were completed within the budget available from the TRIG project. In collaboration with the owner of site 1002, tree marking was completed to assist with the thinning works.

The thinning technique 'thinning from below" was utilised on the two sites. This technique removes the malformed, sub-dominant and co-dominant trees first until the stocking target has been reached which will ensure that the best stems remain to grow on. At site 316, the operations also utilised the technique of out-row thinning to allow for machinery access.

Table 4- Thinning site details

Site	Species	Area (ha)	Current stocking (stems per ha)	Target stocking (stems per ha)
275	*E. occidentalis*	5.6 ha	575	
	E. cladocalyx	2.1 ha	575	
316	*E. tricarpa*	2.04 ha	283	200
	E. tereticornis	2.4 ha	608	200
	C. maculata	3.6 ha	400	200
1002	*E. melliodora*	0.96 ha	650	
	E. occidentalis	5.51 ha	975	

7.4 Remeasure of a Victorian Government provenance trial

Although late in the project, we were provided with a portable storage device that contained considerable information on a range of Victorian Government (was Department of Primary Industries, now Agriculture Victoria, Department of Energy, Environment and Climate Action) trials. We identified a site that contained two provenance trials (*E. cladocalyx* and *C. maculata*) that were planted in 2001 as part of the Australian Low Rainfall Tree Improvement Group project. These trials were remeasured in 2012 and a remeasure now will provide a valuable, up to date, dataset for future analysis.

7.5 Signage for demonstration sites

A number of sites were identified as being suitable demonstration sites, having consideration of the following criteria:

- Species on site
- Site access
- Site proximity to population hubs (such as Melbourne, Geelong, Ballarat etc.)
- Willingness of landowners to allow access.

It should be noted that the organisers of future events will need to actively engage with the owners before committing the site to an event.

To assist with future field trips and demonstration days, signage with stand information has been installed at the sites listed in Table 5. Each sign provides the species name, common name, year of establishment and thinning status (where appropriate), see Figure 12 as an example. Each sign was fixed to a treated pine plinth and square post.

Table 5- List of signs installed

Site	Species	Common name	Year of Established.	Thinning status
11	*Eucalyptus grandis*	Flooded Gum	1993	
11	*Eucalyptus saligna*	Sydney Blue Gum	1993	
113	*Corymbia maculata*	Spotted Gum	1995	
113	*Corymbia maculata*	Spotted Gum	1995	
113	*Corymbia maculata*	Spotted Gum	1995	
209	*Corymbia maculata*	Spotted Gum	2001	
275	*Eucalyptus cladocalyx*	Sugar Gum	2001	
275	*Eucalyptus occidentalis*	Swamp Yate	2001	
316	*Corymbia maculata*	Spotted Gum	2000	Thinned
316	*Corymbia maculata*	Spotted Gum	2000	Unthinned
316	*Eucalyptus tereticornis*	Forest Red Gum	2000	Unthinned
316	*Eucalyptus tereticornis*	Forest Red Gum	2000	
316	*Eucalyptus tricarpa*	Red Ironbark	2000	Thinned
1002	*Corymbia maculata*	Spotted Gum	2007	
1002	*Eucalyptus cladocalyx*	Sugar Gum	2007	
1002	*Eucalyptus cladocalyx*	Sugar Gum	2007	
1002	*Eucalyptus cladocalyx*	Sugar Gum	2007	
1002	*Eucalyptus globulus ssp. bicostata*	Southern Blue Gum	2007	
1002	*Eucalyptus globulus spp. maidenii*	Maiden's Gum	2007	
1002	*Eucalyptus melliodora*	Yellow Box	2007	

Site	Species	Common name	Year of Established.	Thinning status
1002	*Eucalyptus occidentalis*	Swamp Yate	2007	
1003	*Corymbia maculata*	Spotted Gum	2004	Thinned
1003	*Corymbia maculata*	Spotted Gum	2004	Unthinned
1003	*Eucalyptus cladocalyx*	Sugar Gum	2004	
1013	*Acacia implexa*	Lightwood	2002	
1013	*Acacia implexa*	Lightwood	2011	
1013	*Acacia melanoxylon*	Blackwood	2002	
1013	*Casuarina cunninghamiana*	River She-Oak	2002	
1013	*Corymbia maculata*	Spotted Gum	2002	
1013	*Corymbia maculata*	Spotted Gum	2002	
1013	*Corymbia maculata*	Spotted Gum	2008	
1013	*Corymbia maculata*	Spotted Gum	2008	
1013	*Cupressus macrocarpa*	Monterey Cypress	2002	
1013	*Eucalyptus globulus*	Tasmanian Blue Gum	2010	
1013	*Eucalyptus globulus*	Tasmanian Blue Gum	2010	
1013	*Eucalyptus muelleriana*	Yellow Stringybark	2002	
1013	*Eucalyptus muelleriana*	Yellow Stringybark	2002	
1013	*Eucalyptus nitens*	Shinning Gum	2010	
1013	*Eucalyptus nitens*	Shinning Gum	2010	
1013	*Eucalyptus obliqua*	Messmate	2002	
1013	*Eucalyptus tricarpa*	Red ironbark	2000	
1013	*Eucalyptus tricarpa*	Red ironbark	2002	
1013	*Eucalyptus tricarpa*	Red ironbark	2002	

Figure 12- Sign plaque example

8. Project data outputs

8.1 Access database

The Microsoft Access database that was provided at the start of the project has been added to and updated wherever possible. The following updates have been completed:

- Updated contact details of landowners
- Communications records with landowners
- Works including site inspections, inventory, thinning and signage have been added

8.2 Web site

A website for the TRIG project has been created to host the report, interactive online map and case studies. The website will be hosted by Forestry Australia.

8.2.1 Interactive online map

An interactive web map has been developed (Figure 13) that utilises the productivity mapping and inventory results. The web map allows for interaction with the data, and to see what species are likely to be more suitable at a particular location.

Figure 13- Layout view of the TRIG web map

When a user zooms in and clicks on a specific location, a window pops up that provides information about that point. The information includes the National Plantation Inventory Region ID (where applicable) and the 10-year average rainfall (Figure 14), as well as information from the productivity modelling and inventory results.

Central Victoria

National Plantation Inventory Region: Central Victoria
10yr average rainfall: 750 - 800

Figure 14- Web map header example

The productivity modelling data for *C. maculata* and *E. cladocalyx* is significantly more detailed than the data for the remaining species. Therefore, the two datasets are presented separately.

Figure 15 is an example of the information output from the productivity modelling work that created two productivity maps. The productivity mapping information gives an estimated 'species potential' growth for the site and a diameter (DBH) estimate at 25 years. Methodology for this data can be found in Section 6- Productivity mapping

Species Info

The diameter at breast height (DBH) estimates in the table below are derived from 3PG which is a process-based stand growth model. The model was refined using recent inventory data for the two species listed. The inventory dataset was small (52 plots for *Corymbia maculata*, 23 plots for *Eucalyptus cladocalyx*), therefore the DBH estimates should be considered with this in mind.

For the estimates, the silvicultural regime for both species was:

- Initial stocking 800 stems per hectare (sph)
- Thinning to 500 sph at age 5
- Thinning to 200 sph at age 12

DBH estimates are at age 25.

Species	Common Name	Species Potential	Dbh
Corymbia maculata	Spotted Gum	Very Good	35-40cm
Eucalyptus cladocalyx	Sugar gum	Good	30-35cm

Figure 15- Productivity mapping species information example

Figure 16 is an example of information based on the inventory work completed in the project. The species potential was determined based on the distance the selected location is from a known stand of that species (0-50km & 51-100km). This method is less robust than the productivity methodology, but it will give users an idea of which species may be more suitable to grow in the selected location.

Other Species Info

The table below table displays other species which have the potential to grow at this site. The 'Species potential' classification is derived from nearby plantations that have the same species which were in December 2022.

Species	Species Potential
Eucalyptus melliodora	Good
Eucalyptus occidentalis	Moderate

This information is a guide to assist your initial research and is provided for general reference only.

Other species may also grow on this site. Common commercial plantation species across Victoria are *E. globulus, E. nitens* or *P. radiata*.

Specific site investigation and research should be undertaken.

Seek professional advice to maximise achieving your plantation aspirations.

Figure 16- Other species information example

8.2.2 Case studies

Case studies have been developed from willing landowners during the project. The case studies will appear on the website and be available in pdf format.

9. 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.

9.1 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 17 and Figure 18). 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 17). Each generation is composed of a broad base population and a narrower selected population (Figure 18). 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 9.2 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.

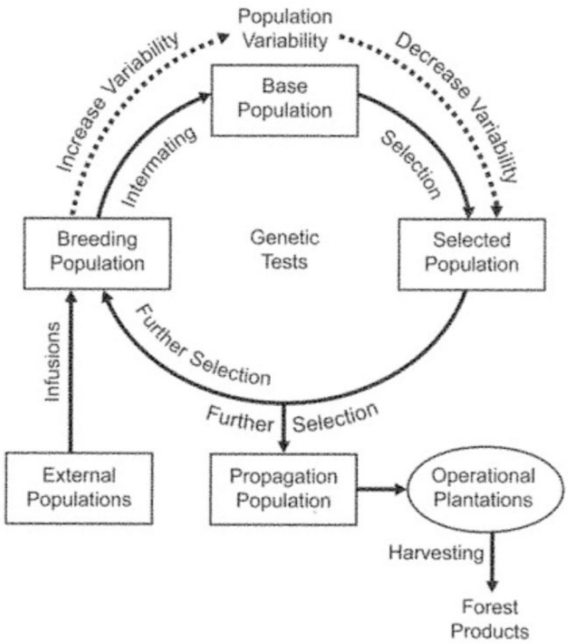


Figure 17- The breeding cycle of tree improvement programs. Each of the core population types shown in the inner circle are formed once per cycle of improvement in the sequence shown, while other population types may or may not be formed. (Reprint of Figure 11.1 from White et al. 2007)

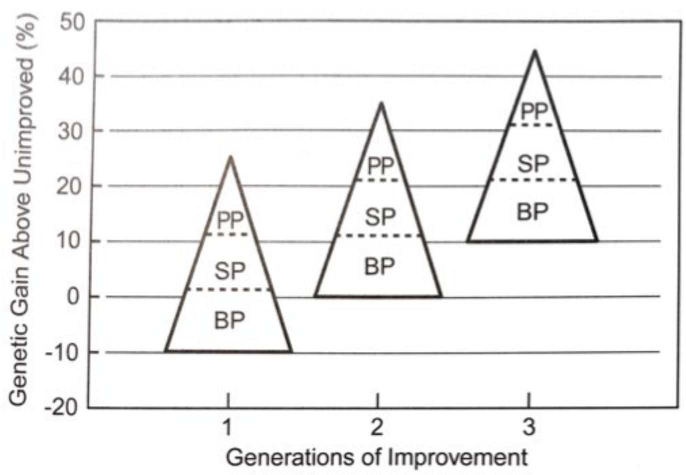


Figure 18- Schematic diagram showing genetic gains for three population types in each of three different cycles of improvement. The entire triangle represents the base population (BP) for each generation. The next smallest triangle represents the portion of the BP that is the selected population (SP), 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.

9.2 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.

9.3 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.

9.3.1 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.

9.3.2 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.

9.3.3 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.

10. 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 6 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 6 - 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 7).

Table 7 - 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.*

11. Carbon markets

Tree plantations are recognised as having significant potential to sequester carbon and there are several options for claiming the carbon credits that plantations can generate. This section describes these options.

11.1 Regulated and unregulated pathways

Regulated and unregulated pathways for conducting carbon projects are available to landholders. When deciding the which pathway to follow, project proponents may consider a range of factors including:

- Access to markets
- Supporting 'claims' for products or services
- Administrative burden (time and cost)
- Commercial viability (which is connected to scale of the project)
- Technical knowledge
- Permanence requirements and encumbrances on land.

Table 8 provides an overview of three pathways for undertaking carbon projects in Victoria. The three pathways are:

1. Emission Reduction Fund - this is a highly regulated pathway that is administered by the Clean Energy Regulator. Within the ERF there are many carbon sequestration 'methods' that are recognised as legitimate by the Federal Government. The 'Plantation Methodology' is one of these methods.
2. Climate Active® is a voluntary reporting method that certifies businesses that can demonstrate that they are carbon neutral, i.e. the business has measured it's emissions, reduced them wherever possible and offset the remaining emissions. These businesses are audited by an independent assessor, and the business publicly reports on their claim. Climate Active released a draft Guideline for Accounting for Carbon Sequestration from Tree Plantings in September 2022. The information in Table 8 is based on that draft guideline.
3. Insetting is also a voluntary reporting method that refers to activities that take place on land within the operational control of a business that reduces net emissions by sequestering carbon. Rather than have external guidance, the business develops its own methods and demonstrates their claims through transparent reporting.

Table 8- Comparison of regulated and unregulated carbon project pathways

	Regulated 'ERF' Plantation Methodology	'Climate Active'	Landholder Insetting
Commercial production	Yes	No (up to 10% harvest for own use)	Yes
Carbon Market options	Available markets – carbon Aust Govt ERF Auctions Safeguard Mechanism Credits Voluntary market carbon offset Support own product/emission reduction claims	Carbon not tradeable Only used to reduce emissions profile against the product or organisation emissions certified under the Climate Active® License Agreement	Carbon not tradable Used to support producer's claims regarding reducing and insetting on-farm emissions
Timber market	Harvesting regime in management plan	No commercial harvesting permitted	Harvesting permitted
Project baseline and newness	No vegetation meeting definition of a forest prior 7 years	No vegetation for up to 5 years prior to the 'commencement date'	Baseline is prior year
'Newness' requirement	Project has not commenced prior to applying for registration.	Project commenced after 1990	No requirement for newness as measuring net abatement
Reporting requirements	Nominated on application (up to 5 years) and determined by the Regulator	Annual	At landholder's discretion and according to the market they are seeking to access
Audited	Yes	Yes	At landholder's discretion

Neither the Climate Active® pathway nor the 'Landholder insetting' option generate tradeable carbon credits, but they do provide the business with an opportunity to demonstrate their carbon neutrality. This may open up new markets to these businesses. In the context of this project, we have focussed on the 'regulated' ERF Market as it provides the landowner with the option to recognise the value of the carbon sequestered.

11.2 Australian Government – Emissions Reduction Fund Scheme

The Clean Energy Regulator (CER) is the Australian Government body responsible for accelerating carbon abatement in Australia. It administers the:

- National Greenhouse and Energy Reporting Scheme
- Renewable Energy Target
- Emissions Reduction Fund.

The Emissions Reduction Fund (ERF) is a scheme that incentivises organisations and individuals to adopt new technologies or change their practices to reduce their emissions. Regulatory instruments give the CER their powers to administer the ERF on behalf of the Australian Government:

The CER:

- develops ERF methods to measure and accredit carbon abatement
- registers projects
- issues Australian Carbon Credit Units (ACCUs)
- runs auctions for the purchase of ACCUs on behalf of the Australian Government
- manages carbon abatement contracts
- maintains a register of projects.
- maintains a register of credits issued to projects.

11.3 Establishing Plantations for Carbon - State Planning requirements

11.3.1 Victorian requirements – carbon

There are no specific requirements for registering ERF projects under Victorian Law. Landholders and project proponents can register interests in carbon property rights on title under the Climate Change Act 2017.

11.3.2 Victorian Timber Planning requirements

Timber production is authorised in areas designated as farming zones. In these areas, timber production within plantations larger than 5 hectares must meet the requirements of the Victorian *Code of Practice for Timber Production 2014* (Code of Practice).

Local Government Regions may have discrete requirements in addition to the framework shown below. For example, within the East Gippsland Shire, plantations larger than 100 hectares require a planning permit whereas there are no other size restrictions specified in other Gippsland shires.

An overview of the various planning requirements is shown in Figure 19.

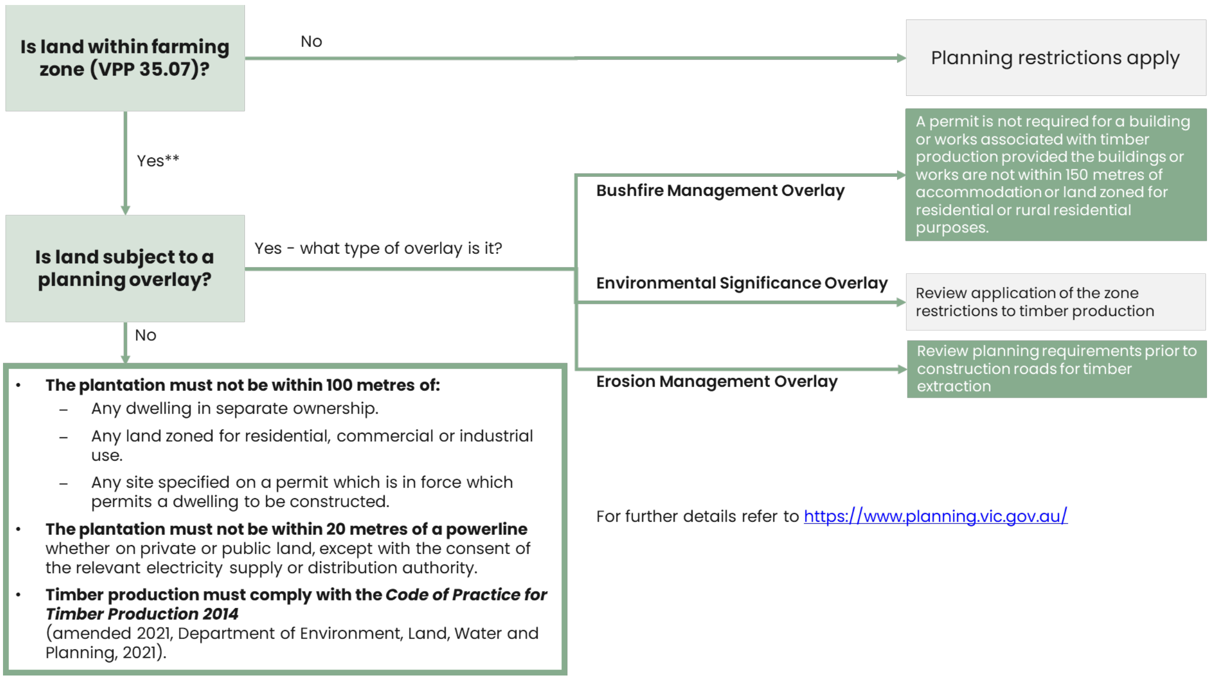


Figure 19- Planning requirements for timber plantations greater than 5 hectares in size

11.4 Actual participation under the Plantation Method for carbon in Australia

Analysis of the ERF Register[1] Vegetation projects account for more than half (~69 million) of all (123 million) CER ACCU's issued under the Emission Reduction Fund scheme to date. Plantation projects (Figure 20) make up a small percentage of all vegetation projects.

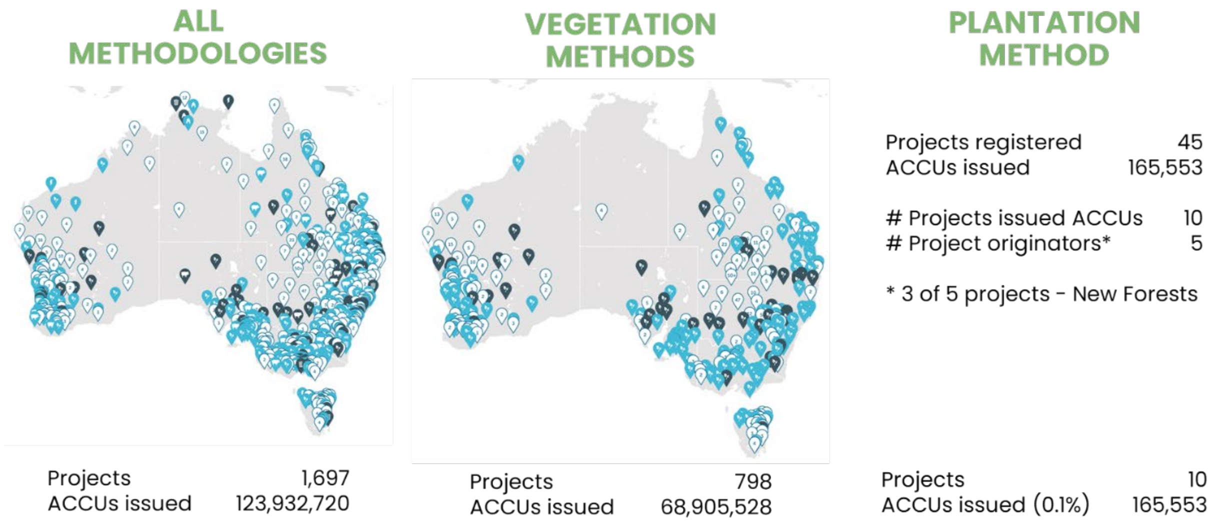


Figure 20 - ERF Registered projects

11.5 Current CER Plantation projects in Victoria

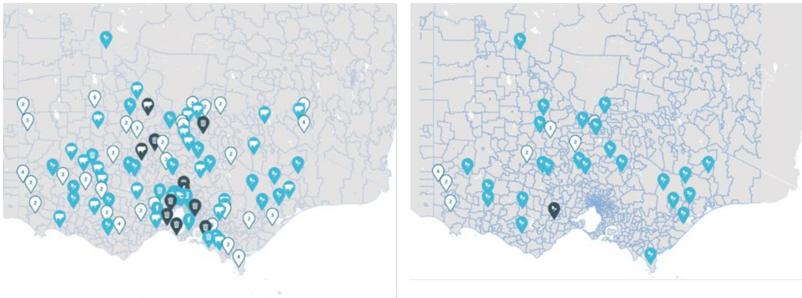
There are eight active projects registered under the Plantation Methodology with the CER in Victoria as of 29 January 2023. There are also two projects that list Victoria as one of the States in which the project is registered. Analysis of the ERF Project Register shows that three of the projects are registered under the Plantation Method and account for 0.9% of all ACCUs issued in Victoria to date (Figure 21).

[1] Source – ERF Project Register ('last updated file 29/01/2023).

ALL METHODOLOGIES

VEGETATION METHODS

PLANTATION METHOD



Projects registered	10
ACCUs issued	87,381
# Projects issued ACCUs	3
# Project originators*	6

- 4 of 10 projects - New Forests
- 4 of 10 projects – Landari/We Act

All methodologies:

Projects	180
ACCUs issued	9,584,275

Vegetation methods:

Projects	180
ACCUs issued	9,584,275

Plantation method:

Projects	10
ACCUs issued (0.9%)	87,381

Figure 21 - ERF Project registered in Victoria

Victorian registered Plantation Method projects cover 10,288 hectares in total. The breakdown of the projects is shown in Table 9. No projects are registered under the 'Farm Forestry' method in Victoria and, as Table 9 shows, only 650 hectares (or ~7%) of all projects are new plantations.

Table 9- Breakdown of ERF registered plantation projects in Victoria

	# projects	Area (ha)	ACCUs issued
Schedule 1 – new plantations	4	650	nil
Schedule 2 – short to long	4	9,638	87,381
Schedule 3 – avoided conversion	-	nil	nil
Schedule 4 – transition to permanent	-	nil	nil

The Plantation Method was approved late in 2017 (and was updated in January 2022) to include Schedules 3 and 4. Projects have five years from the project registration date to produce a report. Some projects that do not have ACCUs issued against them may currently be in the process of independent review and reporting.

11.6 Issues impeding registering carbon projects

The forest products industry has identified the following issues which impeded registering carbon projects under the Emissions Reduction Fund (ERF) in Victoria. Suggested reasons are outlined below.

11.6.1 Administrative complexity requires scale

- Special 'technical knowledge' for registering and reporting against projects and administration of complex and burdensome rules. Current rules mean that reporting and audit requirements are similar whether the project is large or small which means only larger projects are likely to progress.
- 'Aggregating projects' models to service small land holders have not been popular to date. The potential to reduce costs through an aggregation model are somewhat limited because the initial effort to conduct due diligence, mapping and obtain legal rights are the same for each land holder. There are also administrative costs associated with maintaining a project that involves a number of land holders, particularly when land is added or removed from a project (Keenan, et al., 2020).

11.6.2 Competing use of land

- Current land prices are very high and competing agricultural land uses are high making it more challenging for forestry crops to compete with alternative land uses, especially in less productive areas or areas closer to major cities.
- The perception that plantations are a 'threat to agriculture' (note 650 hectares to create 'new plantations' are currently registered under the Plantation Method).

11.6.3 Risk for 'long crops'

- Disruption of the carbon market due to political interference and unexpected announcements means that 'long crop' projects are perceived as higher risk.
- The commitment for managing the plantation over the length of the permanence period. (All Victorian projects have a 25-year permanence period).
- Lack of transparency of the market values of timber (and to a lesser extent carbon) which provide confidence that there will be a market for tree crops on harvest.
- Large upfront capital investment for establishment with lack of certainty that carbon will bring positive cashflows faster.
- Long commitments and the land holder caries the risks that include fire, price stability in market and political stability in the scheme.

11.6.4 'Easier' forms of abatement first

- Project originators have focused on projects that deliver 'instant credits' (gas flaring, avoided deforestation, savannah burning), rather than longer term vegetation projects.

11.6.5 Timber industry slow to respond to the market

- Lack of 'whole of industry' approach and the 'revegetation' for carbon debate has focused on environmental plantings.
- Plantation method was not approved until late 2017.
- The obstruction of the 'water rule', (which was introduced into the regulations in 2015) meant that most of Gippsland would have to pass additional hurdles to show no impacts by projects on catchments stifled project development. The regulations to allow Gippsland projects to proceed without needing to meet this additional hurdle were updated in 2021.
- Lack of recognition of the co-benefits (including water quality, biodiversity, employment, renewable materials, agricultural land productivity) with government and investors that can be achieved without impacting agricultural production.
- Lack of strategic partners (e.g. construction industry, CFMEU, farmers) to push the case – this is now changing.

11.7 Opportunities to leverage plantation timber for carbon

The Australian[2] and State Governments[3] are pushing the merits of 'farm forestry' to expand the plantation estate. As shown above, threshold issues such as the transactional costs and administrative burden in registering, reporting and particularly auditing means that projects need to be undertaken at scale to be commercially viable. The paradox is that farmers (as a rash generalisation) have not undertaken projects at scale.

[2] Commonwealth - Plantations and Farm Forestry- https://www.agriculture.gov.au/agriculture-land/forestry/australias-forests/plantation-farm-forestry
[3] Gippsland farm forestry- https://www.vicforests.com.au/vicforest-forest-management/farm-forestry

11.8 Overcoming the scale (project area) barrier to leveraging carbon to expand the plantation estate.

We have considered three pathways for overcoming the barriers of commercial viability for smaller projects. A brief benefit analysis is provided for each pathway. The pathways are:

1. Project aggregation
2. Integrated Farm Methodology (in development)
3. Small project – alternate assurance arrangements

11.8.1 Project aggregation

Project aggregation means pooling projects from numerous smaller projects and registering them as a single project with the aim of creating efficiencies of scale in project costs. They may include:

- Ordering stock
- Engaging contractors
- Project monitoring and management
- Reporting
- Auditing costs
- Registering with the project/liaising with the regulator

In practice, discussions with several 'aggregators' said that it is very challenging to create a commercially viable model. The barriers mentioned included:

- No significant savings on audit fees (one provider noted that the auditor charged more).
- Poor performance or withdrawal by a project member imposes a liability on the rest.
- Joint 'permanence' period on a project means it is likely that members of the aggregated project will withdraw with little opportunity to add more members without impacting the permanence period of the project.

11.8.2 Integrated Farm Methodology

The Integrated Farm Methodology (IFM) was drafted by the CER and consultation on the draft method received. The IFM allows for different methods (for example soil and farm forestry) to be 'stacked' under the same project. The Plantation method is not currently included in the IFM method.

The Method is currently 'on hold' as the Government has accepted the recommendations of the Chubb review, that included:

- Changing responsibility for method development from the CER to the Department of Climate Change, Energy, Environment and Water (DCCEEW). This change is in progress.
- Establishing the CAIC (Carbon Abatement Integrity Committee) to assess and make recommendations for the approval of methods. Creation and recruitment to the CAIC demands a legislative change. This is unlikely to occur before the Safeguard Mechanism legislative updates are passed.

The delay provides an opportunity for the Plantation Method to be included in the IFM (or at least a pathway for its inclusion to be developed).

11.8.3 Small project – alternate assurance arrangements

All CER registered projects are subject to integrity measures which include audit requirements however, the original scheme design did not have 'fit for purpose' provisions. In response, the Australian Government proposed that the administrative costs of carbon projects were reduced after recommendations from the King review. However, these changes are only applicable to environmental plantings that are less than 200ha.

There is an opportunity for the Forestry Industry to advocate for similar changes to small farm forestry projects registered under the plantation method - given the ability to monitor progress and status of projects using remote sensing technologies. Small plantation projects are generally considered to be of a comparable or lower risk then stand-alone environmental plantings. Yet are still subject to the larger administrative burdens. The industry could advocate for these changes whilst maintaining an appropriate level of assurance that is fit for purpose and does not reduce scheme integrity.

12. Biodiversity markets

Biodiversity markets are most commonly related to developments that will cause environmental damage. In these circumstances, a developer will seek to purchase an equivalent offset to the proposed development. In most cases the offset is natural vegetation that is under a conservation covenant to guarantee that the offset is in perpetuity.

The Victorian Government have coined the term 'EcoMarkets'[4] to describe a range of market-based systems that help to reduce impacts on the environment. Examples of EcoMarkets in Victoria are:

- BushTender - focussed on existing areas of native vegetation and provides landholders with payments to make improvements to these areas.
- EcoTender - similar to BushTender but broadens the reach to include financial incentives for improving rivers and estuaries.
- BushBroker - a platform for linking landowners who have developed native vegetation credits with developers who need to purchase credits to offset their development.

In terms of the establishment of tree plantations for commercial production and many other values, it is unclear if such tree plantations could participate in these EcoMarkets.

At the Federal Government level, a new market is under development called the Nature Repair Market[5]. The aim is similar to the Victorian initiatives; provide a method for companies and businesses to reward landowners to make environmental improvements to their land. This new market is going through a consultation phase in 2023 with the aim of having the market operating by mid-2024.

One of the key requirements to any claim of biodiversity improvement is to be able to demonstrate the change that has come from the activity. To demonstrate change, a baseline situation must be measured and recorded. Tree plantations are a definite improvement to biodiversity when compared to grasslands, and we expect that markets will reward such improvements in the future. It will be imperative to actively measure and record these improvements over the 'baseline'.

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[4] https://www.environment.vic.gov.au/innovative-market-approaches/ecomarkets
[5] https://www.dcceew.gov.au/environment/environmental-markets/biodiversity-market

13. Conclusions

The TRIG Project was conducted over the course of 14 months and covered a range of aspects pertinent to capturing and updating knowledge on a range of potential plantation trees for farmers.

The project delivered on its purpose, namely:

1. The farm forestry trial database was updated with new trials and information gathered during various stages of the project. Priority sites were identified, inventory conducted, and works completed.
1. A number of model plantings were identified which, with the agreement of the landowners, can be used as demonstration sites. These sites have had signage installed to aid with interpretation and to publicise their presence.
2. The availability of seed for the shortlist of promising seed was explored. It was discovered that there is generally a plentiful supply of seed and that sufficient orchards already exist.
3. As well as this report, a webpage has been created that includes case studies and an interactive map that helps identify species for farm forestry.

14. Recommendations

- The trials associated with the Australian Low Rainfall Tree Improvement Group are comprehensive and cover sites not just in Victoria, but in South Australia and New South Wales. All sites should be remeasured, and the results analysed to enable identification of the best progeny for each species.
- The web map that has been created from results of this project could be refined with further information and expanded to include other species. It may be possible to utilise trials information from other States and relate these to climate data in Victoria.
- The farm forestry database is a valuable source of information that needs to be maintained and updated as new information becomes available. The most suitable owner and manager of this database should be determined.
- Tree improvement through breeding is an activity with long lead times and requires specialists who can ensure that improvements are achieved. These activities should be done in collaboration with experts in the field of tree breeding.
- Explore Victorian government research sites' paper-based records and digitise this information for greater access. We believe that there are key information stores that provide details of trial layouts and completed establishment works.
- Expand on the species available for 3PG modelling by capturing the necessary data. This requires a detailed measurement of perhaps a dozen destructively harvested trees on multiple sites, including excavation of roots to 2 mm thickness. This future work is highly recommended for alternative species that can be identified with commercially viable prospects for timber and carbon.

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Appendix A - Site inspection form

Site Info:

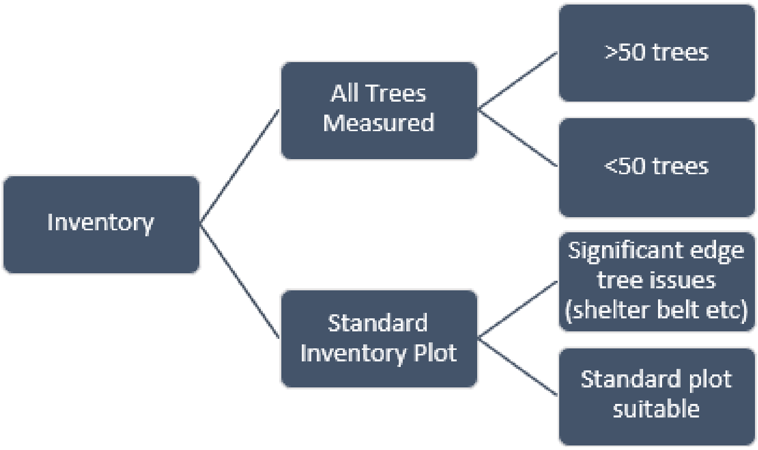
Site ID:	
Owner Name:	
Owner Phone:	
Species:	
Hectares:	
Year:	
Trial Theme:	
Reason for Planting:	
Property:	
Address:	
Town:	
Easting:	
Northing:	
Latitude:	
Longitude:	
Comments:	

Quality:

Overall health of trees for age?	
Visible signs of damage?	Insect, disease, fire, other
Damage comments	
Major deformity present?	Excessive taper, excessive branchiness or sweep
Deformity Comments	
Seed Orchard Potential?	Y/N/NA
Seed Orchard Comments	
Demonstration Site Potential	Y/N/NA
Demonstration Site Potential Comments	
Works Suggestion Comments	

Measurement Potential

Is stand worth an Inventory Survey?	Y/N		
How well is the site marked for treatments/plots/trial design?	*Pegged out, obvious areas identifiable*		
Does the owner have any design information?			
Inventory style suggested?	All Trees Measured	OR	Standard Inventory Plot
If 'All trees Measured' style selected, does the stand have?	<50 trees	OR	>50 trees
If 'Standard Inventory Plot' style selected, does the stand have?	Significant edge tree issues (shelter belts, narrow planting?	OR	Standard plot suitable

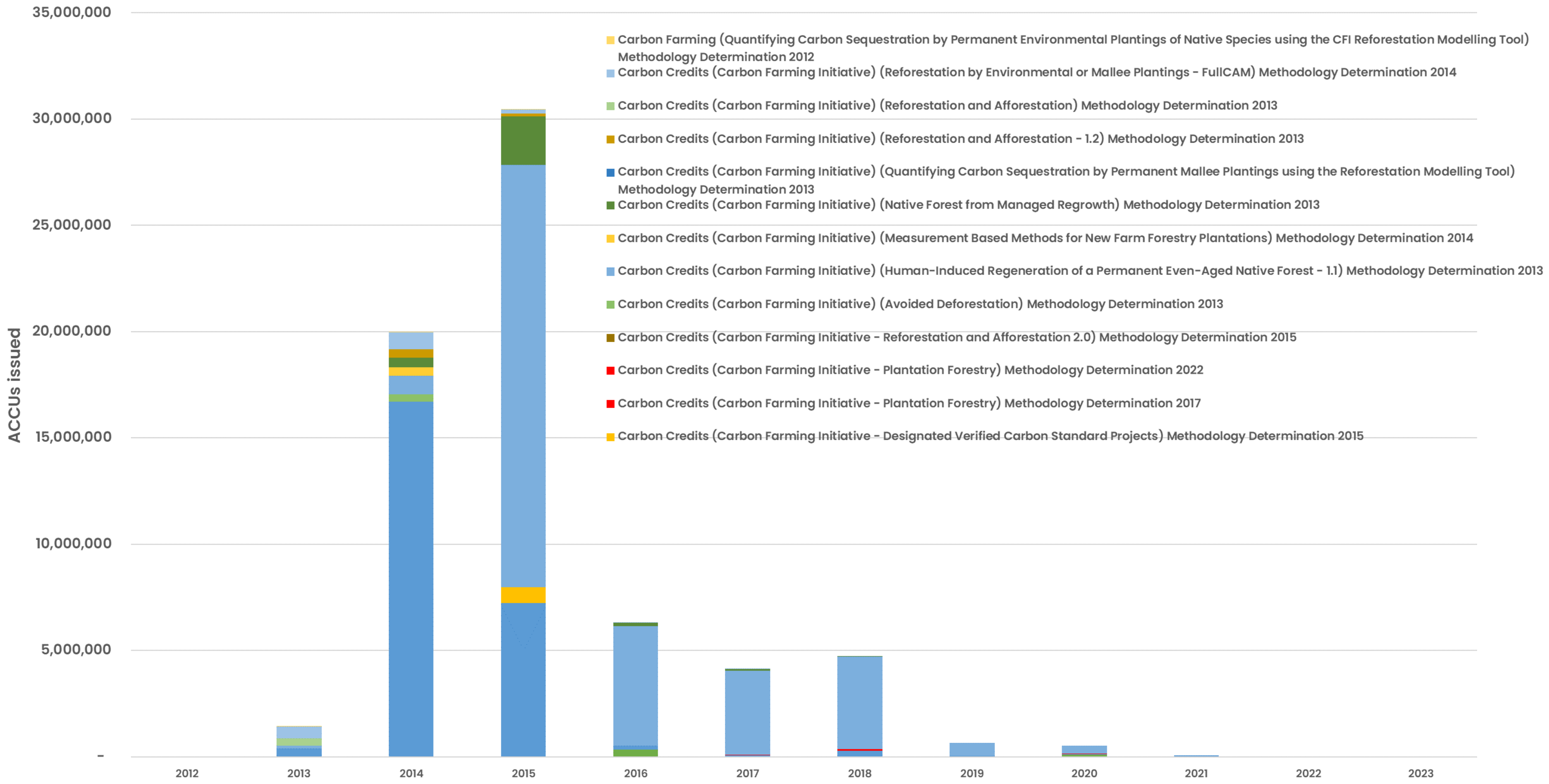


Site Access and Hazards: (EDITABLE)

Does the site have easy access for Inventory Contractors? Comments	
Does the site have any hazards which an Inventory Contractor will need to be aware of? Comments	

Appendix B - ERF Registered vegetation projects

Number of ACCUs issued against all the various ERF registered Vegetation methods. ACCUs issued against the Plantation Forestry method projects are shown in red.



Appendix C – Works photos

Lake Tyers site 316 - *Corymbia maculata* photo before (left) and during (right) thinning. Thinning residues have been mulched to retain nutrients in the soil and remove hazards for stock grazing in the future.

Lake Tyers thinning operation in progress within the *Eucalyptus tricarpa* stand. A compact harvesting machine is being utilised to minimise potential damage to remaining stems.

Appendix D – Case Study

Name: Michael Wright

Property: Nula Vale

In the year 2000 Michael bought a property and consulted with professionals to understand the land and its best uses. Initially he hoped to grow walnuts in conjunction with forestry plantings, however, they failed due to a lack of water. The infrastructure from the walnuts was later utilised to support a fruit orchard.

Michael then engaged a team of permaculture specialists which included surveyors who planned the water movement across the site for dam locations and planting locations. By 2002 Michael was ready to undertake the first plantings. The permaculture team also involved a tree planting expert who assisted with species selection and provenance of the seedlings.

The purpose for the forestry plantings was to supply specialist timbers for furniture manufacturing. Trees grown for this purpose are usually managed by high pruning to produce knot-free timber, and the plantation is thinned to promote growth. Michael's objective was to produce a site that did not consist of a mere monoculture. This mixed plantings approach across the site was intended to promote biodiversity and enhance environmental habitat. The furniture timbers were initially inter-row planted with Blackwattle to provide protection for the seedlings. The Blackwattle has since progressively been removed after the timber species had overgrown them.

The forestry plantings across the site bring many commercial and environmental benefits. Commercially viable stands of furniture grade timbers are to be selectively harvested in the future. There will be no clear-felling of stands. Environmentally, the site has seen an enormous increase in birdlife and animals.

The site now also benefits from significant cooling effects from the plantings. Small areas of erosion have been managed with environmental plantings to stabilise the soil, although there are not many of these areas. Michael believes the site was only cleared of vegetation for agriculture in the 1930's and 1940's.

Nula Vale site before (left) and after (right)planting

Michael and his wife have registered with the Birdlife Australia program, Birds on Farms. Four plots are measured four times a year. Surprisingly high levels of returning species have been observed. Michael is also an active member of the local land care group that runs farmer enrichment and training courses in the local area. This group also undertake projects like physical pest species removal, such as Blackberry.

In recent years Michael has engaged with professional forester, Gary Featherston (Forest Strategy Pty Ltd) to help with the management of the forestry plantings on site, including thinning regimes, stand inventory and future planning. The forests are certified as sustainably managed via Gary's group certification scheme.

Location		85kms north of Melbourne CBD
Annual rainfall		650-700mm
Property size		140 acres or 57 hectares
Enterprise type		Forestry
Property characteristics		• 1/3 of the productive are planted into forestry • 2 paddocks • Fairly steep in parts
Species planted on-site	*Cupressus macrocarpa*- Monterey cypress *Eucalyptus globulus*- Tasmanian blue gum *Eucalyptus nitens*- Shinning gum *Corymbia maculata*- Spotted gum	*Acacia implexa*- Lightwood *Eucalyptus obliqua*- Messmate *Eucalyptus muelleriana*- Yellow stringybark *Casuarina cunninghamiana*- River she-oak