Maritime pine for dry-land Western Australia.

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Abstract

A Maritime pine breeding program commenced in Western Australia in 1957, to ameliorate defects in *Pinus pinaster* for wood production on high rainfall areas of the Swan Coastal Plain. Substantial gains in tree growth and stem and branching form have been provided to plantations since 1971.

In 1996, the Salinity Action plan, Maritime Pine project, proposed to use *Pinus pinaster* as a commercial tree crop to combat salinisation in the medium-low rainfall zone of Western Australia. It was planned to establish 60,000 ha over the next 10 years to demonstrate the capacity for the commercial viability of the species as an alternative land use.

Tolerance to low rainfall was a major breeding objective. On the Swan coastal plain, unthinned family trials carrying very high basal areas when extreme droughts occurred in 1994 and again in 2001, provided selections for a new round of clonal seed orchards for deployment to dry-land.

The challenge was to take the developed, diverse breeding population to new sites in the medium rainfall areas of the wheat belt and to test the suitability of genotypes being deployed and to provide a new selection base. Some 32 progeny trials on an area of 55 ha, testing 843 families with 81,380 progeny were established over the next decade.

Although the main breeding activity has focused on the improved Leirian variety, access to other *P. pinaster* sources, hybrid development and alternative species are reviewed in this paper.

Introduction

Pinus pinaster (Maritime pine) was first planted in trials in Western Australia in 1896. Provenance trials were planted at Gnangara in 1926 and were conclusive in showing *P. pinaster* from Portugal (Leiria) as having the best growth rate and reasonable form for sandy soils of the Swan Coastal Plain. Breeding program commenced in 1957 to select dominant, fast growing trees with good form (Perry and Hopkins, 1967). It was very successful with genetic gains or yield trials showing trees to be 40% more productive as well as straighter and smaller limbed, compared to the original unimproved stock (Butcher and Hopkins, 1993; Hopkins and Butcher, 1994). State owned plantation estate on the Swan Coastal Plain totals more that 27,000 hectares with half of this originating from clonal seed orchard.

Western Australia has an enormous dry-land salinity problem, with reports of 1.8 million hectares of agricultural land already affected and about 6 million hectares at risk due to broad scale clearing of woodland for agriculture since European settlement

(Agriculture WA *et al.*, 1996). To combat this problem, the State Salinity Strategy, identified the need to plant deep-rooted perennial species in the medium and low rainfall zones to drop these rising groundwater tables. *Pinus pinaster* was considered a suitable species due to its ability to grow in the 400-600 mm rainfall zone and to provide a commercial return to landowners. In essence, a major commercial tree crop would be used as a tool to draw down water tables to give the environmental benefits and another source of income to farmers (Shea, 1998). The Maritime Pine Project began in 1996 in response to the State Salinity Strategy. It was planned to establish 60,000 ha over the next 10 years to demonstrate the capacity of the species as an alternative land use. Area actually planted was 19,573 ha.

Current genetic investigations are outlined. These involve selection within the improved *P. pinaster* breeding population, provenance hybrids, alternative species and species hybrids.

Dry-land breeding strategy.

Use of the existing, improved breeding population.

Eighty five genetic trials covering an area of 158 hectares and 183,000 trees had been established, mostly on the Swan Coastal Plain to quantify genetic parameters and to provide the selection population for the next round of improvement. Breeding objectives related to principal land use for potable water and quality sawlogs from the Gnangara Mound (Butcher, 1979). Principal traits were stem straightness and form, reduced branch diameter and tree vigour. Tolerance to drought was added as an important trait after the continuing drought events in the early nineties. This was to become a major trait for reselecting a breeding population for dry-land Western Australia.

Butcher (1979) reported two occurrences of stand collapse in the Gnangara plantations. The first was in 1950 and the second in 1977. Both were in dense pine stands, with rainfall in preceding year 25% below average, followed by five months of negligible rainfall. They were also the only years on record where no rain fell in April. Rainfall records for the Gnangara station (latitude $31^{0}47'$, longitude $115^{0}57'$) are no longer maintained but there is very good correlation with nearby settlements (Butcher, 1986). Recent extreme rainfall events are listed in Table 1 for Pearce station (latitude $31^{0}41'$, longitude $116^{0}01'$). These were coincident with unhealthy stands and scattered tree deaths in the mid-nineties and stand collapse at Gnangara and Yanchep in 2001.

Table 1 : Extreme summer rainfall events at the Pearce station.

Year	Dec-	Jan	Feb	March	April	Summer	Annual
1993	9.0	0.0	8.2	5.8	4.6	27.6	678
1994	1.0	0.0	0.4	2.2	2.2	5.8	494
1995	0.0	0.0	27.6	4.8	7.2	39.6	789
1996	7.6	3.4	0.0	1.4	4.6	17.0	783
2001	1.0	0.6	4.4	3.8	6.0	15.8	533
Mean	8.9	10.5	12.5	15.1	34.6	81.6	684 mm

A subset of progeny trials (44 ha) planted in 1975-76 at Gnangara (Neaves) plantation (latitude $31^0$41’, longitude $115^0$55’) had been left unthinned because of the poor site type and growth and the fact that some of these were single-tree family plots. They were assessed in May 1995 for genetic parameters of health and survival. Only 5.8 mm rainfall was recorded in the five summer months of 1994 when Neaves stands were about 90% stocked with basal areas ranging from 25 to 33 m^2ha^{-1}. Rainfall for 1994 was 28% below average and following summer rainfall was 39 mm. Although most trees survived, half of these were scored as unhealthy and there was very good separation on families. Best breeding value trees for health, diameter and form were selected and grafted in November 1995. They were then planted in 1996 in a new orchard unit at Manjimup for deployment to dry-land and in archives. Ortet pollens were also collected in 1995.

Table 2 : Trial average standing basal area m^2ha^{-1} and common *Pinus pinaster* full-sib families, basal area expressed as percentage of the mean for unthinned trials in Gnangara (Neaves) plantation, grouped for a consistent tolerant (tol) or susceptible (sus) response to drought. Trials planted in 1975-76 at 1080 sha^{-1} and assessment in 2002 at age 26-27 years, after the extreme summer drought of 2001.

DRY	FAM	YS54DIF	YS55DIF	YS57DIF	YS59DIF	YS60DIF
tol	1	47		37	48	45
tol	2	33	36	33		20
tol	3	103		71	82	62
tol	4	10	6	25	22	2
tol	5	45		28		47
tol	6	23	45		24	
tol	7			29	27	46
tol	8	60	52			
tol	9		29	28		18
tol	10			58		63
tol	11			58		59
sus	1	-43	-39	-35		-51
sus	2	-36	-5	-35	-63	-52
sus	3		-53	-48		-45
sus	4	-38	-50		-62	
sus	5	-52	-23		-39	
sus	6	-21		-41		-52
sus	7	-39	-27	-36	-21	
sus	8	-6	-9	-32	-25	-35
sus	9	-25	-2	-39		-40
sus	10	-60	-49			
sus	11	-32		-9		-43
BAHA		30 m^2ha^{-1}	26	24	25	24

Stand collapse occurred in Neaves and other trials in 2001 following the negligible summer rainfall but it was even more severe as it was preceded by only 6 mm in October and 16 mm in November for a total seven months rainfall of 37 mm. This gave a good sorting of families and genotypes for this survival trait. Trials were

large, heavily stocked and with good numbers of parents mated in random-pairs to give a good average for the Leiria population. Table 2 presents a sample of families that were usually represented in more than two trials. They are divided into groups for a consistent tolerant or susceptible response for basal area. Standing basal area per hectare is a good indicator of drought response as it includes both tree size and survival. However, in this case it is calculated and not the actual stand value. Family plots were either single trees, line or 4-tree square plots. While this is not ideal, for competition with same family members is not completely possible, the consistency across trials and with different families gives some confidence in the ranking. Also, while not shown in this table, parent response either as tolerant or susceptible was consistent.
A new round of selections was made in 2003 and trees were grafted and established in breeding archives. The best selections for drought tolerance were also included in seed orchard planting for 2005. Information was also used for the control pollination program in 2004.

Provenances of *P. pinaster*.

Pinus pinaster provenance response to drought was reported in Hopkins and Butcher (1993). Provenance trial XS12 was planted at Yanchep (latitude $31^0 29'$, longitude $115^0 41'$) in 1967 at 1736 sha^{-1} using 36-tree square treatment plots. Trees were 10 year-old when the extreme drought hit in 1977, where there was canopy closure in the 21 m^2ha^{-1} Leiria origin plots (Table 3). Mortality was 1 % for Leiria, 12% for Corsica (trees were 64% smaller in volume than improved Leiria) and 9% for Landes provenance (53% smaller). This field response confirmed rankings in the glasshouse trials reported by Hopkins (1971). XS12 plots were thinned to one-third stocking following the drought in 1977. By 2000, stand basal area had developed to 45 m^2ha^{-1} for the improved Leiria but survival fell to 69% because of the very high basal area and extreme low summer rainfall in 1993 and again in 1994 (Table 1). At age 33 years, improved Leiria had volume mai of 12.1 m^3ha^{-1} compared with 9.4 m^3ha^{-1} for unimproved, a gain of 29%. There was also a doubling of number of straight stems and 50% more trees with desirable branching. The tree quality improvements were similar to the gains using the Corsica provenance (Table 3). There was additional collapse after 2001, particularly in the Landes provenance (Table 3).

Table 3: Performance of provenances and improved *Pinus pinaster* at Yanchep trial XS12 planted in 1967.

Year	Trait	Leiria _Imp	Leiria_Un	Landes	Corsica
1977	Basal Area	21 m^2ha^{-1}	19	12	11
	drought	1%	2%	9%	12%
	AT Baha	8 m^2ha^{-1}	7	5	5
1986	Basal Area	25 m^2ha^{-1}	22	14	14
2000	Basal Area	45 m^2ha^{-1}	38	23	24
	alive Baha	37 m^2ha^{-1}	35	20	23
	survival	69%	78%	78%	89%
	stem volume	734 dm^3	570	251	214
	volume mai	12.1 m^3ha^{-1}	9.4	4.2	3.8
	good stems	86%	43%	59%	82%
	good branch	73%	49%	87%	81%

2005	Basal Area	42 m^2ha^{-1}	39	16	24
	survival	62%	75%	42%	79%

Leiria_Imp = improved seedlots from the WA breeding program.
Landes = improved seedlots from Landes France.
Corsica = special seedlots from Corsica.
Leiria_Un = unimproved seed from Leiria Portugal.

An inter-provenance hybrid trial using the same improved Leiria parents crossed with improved Corsica and Landes parents was planted at 1080 sha^{-1} north of Yanchep in 1973. Data from the 2000 measurement is presented in Table 4. Basal area includes trees that died during the drought of 1994-96. As before (Table 3), survival is lower for the Landes and Corsica crosses even though trees are smaller. Crossing with Leiria has significantly increased vigour of the Landes and Corsica parents (Tables 3 and 4). Similarly, the improved branching and form traits of the Corsica tree have been transferred to the Leiria cross. The improved apical dominance of the Leiria * Corsica cross is a trait being studied in a clonal trial planted at Dandaragan in 2001.

Table 4 : Growth at age 26 years for provenance hybrids of *Pinus pinaster*, planted at Yanchep in 1973.

Trait	E * E	Leiria Un	E * L	E * C
Basal Area	54 m^2ha^{-1}	42	39	37
diff	28%	=	-8%	-12%
survival	80%	74%	55%	72%
good stem	76%	43%	70%	91%
good branch	59%	47%	61%	88%
good form	38%	41%	48%	59%

E = Leiria improved. L= Landes improved. C = Corsica improved.
Leiria Un = unimproved seed from Leiria Portugal.

External sources of Leiria provenance.

Another option is to access material from other countries with plantations of Leiria origin *P. pinaster* growing in a low rainfall environment. An important source area is Morocco, where climate of the coastal lowland region is very similar to medium-low rainfall, southwest Western Australia. Average rainfall at Mechra el Kettane plantation is 420 mm but in the 5-year period 1993–1997, rainfall averaged 280 mm. This caused severe drought mortality in the 50-year-old Leirian stand. Butcher (1999) saw this as an excellent opportunity to select healthy, vigorous and good-formed trees that have shown a capacity to survive under prolonged, severe drought conditions. Negotiations are continuing to accomplish this selection and importation. Family trials using WA genetic material were successfully planted in Morocco in 2002.

Establishment of a dry-land breeding population.

A new third generation breeding population was created by control pollination of parents selected for tree form, growth rate and drought tolerance. This new population has been planted on farms in low-medium rainfall, agricultural areas from

Moora to Esperance, commencing in 1997. Over the next decade, 32 progeny trials were established on 55 hectares testing 843 families. Progeny trials usually included 100-250 families and 3-4 unimproved seedlots with a minimum of 24 progeny planted in line plots of 4 trees. Incomplete block designs were used for all trials and trials were repeated on sites in the major production cells (Midwest, Southwest, South Coast and Esperance).

Poster in this proceedings, titled "Improvement of Drought Tolerance of Commercial Tree Crop Species" (Natural Heritage Trust project 983194) sought to improve the profitability of tree crop options for the medium rainfall zone of Western Australia. This NHT project involved the most important pine species to southern Australia – *P. radiata*, *P. pinaster* and *P. brutia,* with the aim to improve drought tolerance. The 12 *P. pinaster* trials occupy an area of 39 ha, 43,000 trees and test 380 new families. These mostly had excellent establishment with 95% survival or better (Butcher, 2003). It is these trials that provide the future base to identify families and individuals with the best performance for survival, form and growth.

Early results and performance.

Problems were expected with drought tolerance, particularly in the northern wheat belt where rainfall is low and evaporation high. The first trial was planted in 1997 at Moora (latitude $30^0$64', longitude $116^0$01', rainfall 462 mm and evaporation 2300 mm). Drought death, 12% of trees, occurred in one corner of the trial when it was assessed in 2005 but it had a low heritability because of its uneven disposition across the trial site. With aging and stand development, this trial will provide a good base for drought genetic parameters. At age 8, basal area was 12 m^2ha^{-1} for improved trees and 9 m^2ha^{-1} for unimproved trees. There were 30% more straight stems, 50% more trees with smaller branches and 16% more healthy trees for the improved stock.

The second trial was planted in the Great Southern at South Stirling in 1997 (latitude $34^0$36', longitude $118^0$07'). It was still 99% stocked when measured early in 2007 at age 10 years. For improved trees, basal area was 27 m^2ha^{-1} and 60% had acceptable stem straightness and branches. Unimproved stand basal area was 22 m^2ha^{-1} and there were 70% fewer straight and 40% fewer acceptable branched trees. All trees were very healthy on this southern site.

Early Esperance progeny trials show that *P. pinaster* has huge potential in this region (latitude $33^0$39', longitude $120^0$58', rainfall 600 mm and evaporation 1700 mm). After 4 years, heights averaged 3.9 m for unimproved compared with 4.4 m for improved trees while best families were 5.2 m and best trees were 6.6 m. Malformation was also minimal on this site. At age 7 years, basal area was 21 m^2ha^{-1} for improved and 14 m^2ha^{-1} for unimproved.

What was unexpected was the apparent early poor form of trees planted on some ex-agricultural sites. Surveys of affected farmland plantings north of Perth showed that up to 60% of trees had malformations such as kinks, forks, large ramicorns, basket whorls, multiple leaders and loss of apical dominance, compared with an average 12% malformation for ex-bush sites in the Yanchep plantation (Carpenter, 2001). Cause appeared to be related to abnormal late-season growth shoots on ex-pasture sites that have an abundant stored soil water and soil phosphorus loading. There is some genetic control of these late season buds, particularly for the slower growing Corsica provenance. The better form of Corsica trees was shown in the provenance trial at Yanchep (Table 3), as was the improved tree form of Leiria crossed with Corsica (Table 4). This is being investigated with clones of provenance and hybrid trees at Dandaragan. Corsica pollens from Afocel's breeding program (Alazard, l989) have been used to cross with our Leiria parents and new trials planted near Broomhill in 2004. Malformation was assessed at age 3 years in dry-land trials and has low-moderate heritability. Best breeding value pedigrees were identified and grafted for new orchard. Carpenter (2003) reported on a study of the genetic and environmental factors in relation to malformation.

Alternative species and hybrids.

The Natural Heritage Trust project 983194 was very successful in the establishment of best genetics trials of *P. pinaster* (39 ha), *P. radiata* (14 ha) and *P. brutia* (8 ha).

Pinus brutia has the potential to be an important commercial softwood in dry-land Western Australia. It has a very high tolerance for shallow, alkaline and acid soils and the ability to survive in areas of very low rainfall and appears to have good control of apical growth.

First progeny trials of Cyprus provenance were planted at Yanchep in 1964 and 1969. As for most *P. brutia* plantings, management of the trials was neglected because of the very slow early growth of trees; they were left unpruned while adjacent *P. pinaster* and *P. radiata* trees were pruned and later thinned. Trees were measured in 1999 for diameter, height, stem and branching form, and best trees cored for wood density. Survival varied but this was due to establishment losses as there was little evidence of recent dead trees. Best families had mai of 10 to 12 m^3ha^{-1} and basic density was 523 kgm^{-3}. In an adjacent heavily thinned *P. radiata* stand, diameters were comparable but trees were shorter and had stem splitting from sunscald. *Pinus pinaster* on a similar site in a thinning experiment had a mai of 9 m^3ha^{-1} for the unthinned treatment but was suffering from drought losses (Butcher and Havel, 1976). Best trees for volume, stem and branching form were grafted in 2000, and then used to plant a seed orchard at Manjimup. Open-pollinated cones were collected from ortets in trials and used to plant dry-land progeny trials in 2002 at 3 sites (Marchagee, Brookton and Esperance).

In the Midwest planting cell, drought tolerance is the major breeding objective. This could be achieved by using *P. brutia* as a pure species or with *P. brutia* as hybrid with *P. pinaster*. This hybrid would combine the drought tolerance and apical dominance of *P. brutia* with the vigour and early establishment of the improved *P. pinaster*, and would be suitable for lighter soils. Hybrid crossing was done in 2002 at the Rottnest Island *P. brutia* clonal seed orchard. Hybrid and pure species families were planted in 2005, in a progeny trial east of York. Survival at 1-year was 88% for the hybrid and was similar for *P. brutia* and *P. pinaster*. Hybrid crossing is continuing.

NHT983194 project funding enabled the successful establishment of 14 ha of pedigree trees from the *P. radiata* Cambria provenance in 1998 at Wandering, Esperance and Pemberton (Butcher, 2003). Cambria provenance is of interest to WA because of its greater tolerance to *Phytophthora cinnamomi*, waterlogging, soil salinity, phosphate deficient soils and drier sites.

Work is continuing in *P. radiata* progeny trials located in medium rainfall / high evaporation areas for selection of trees with resistance to sunscald and good growth and form potential. The local Search85 breeding population will play a major role as parent trees were indirectly selected for drought tolerance.

The current breeding program for *P. radiata* has a priority to enhance drought tolerance. This is being achieved and by crossing within the improved Monterey population and by inter-provenance crossing. In a 7-year-old trial at Wandering, medium rainfall, ex-pasture site, mai at early age for improved *P. radiata* was 14 m^3ha^{-1} compared with unimproved 9 m^3ha^{-1}, and 13 m^3ha^{-1} for Cambria / Monterey hybrid trees. It is the Cambria provenance that FPC has under test to extend the range of *P. radiata* into dry-land Western Australia.

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