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Improvement of *Pinus pinaster* Ait. in Western Australia

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SUMMARY

Pinus pinaster was introduced to Western Australia (WA) in 1896 to reduce import expenditure by providing a local source of plantation softwood timber. The species proved most successful in re-afforestation on sandy soils in the south-west corner of the State which has a climate similar to that of the Landes region of France and to that in South Africa.

By 1940, trials and plantation development with seed imported from Europe and South Africa clearly indicated that the provenance from the Forest of Leiria in Portugal had the greatest production potential on the soils available for plantation. Since 1942, all plantations established for the species in WA have been of Portuguese origin.

Up to 1957 some 4000 ha of the species had been established. These stands performed acceptably for vigour, with appropriate fertilizer additions, but stem form was poor and less than that usual for the slower growing Corsican provenance tested in the area. The major defects were pronounced butt sweep, crooked stems, and relatively heavy, upright branching. Up to 20 per cent of stems planted were subject to double leaders (forking). Although the vigour was generally deemed to be acceptable, it was extremely variable within stands.

In the early stands less than 13 per cent of seedlings planted developed with the acceptable vigour and form required in a managed final crop. Only 2 per cent of the population produced the most desirable plantation tree (ideotype).

To counter these deficiencies in the species, seedlings were closely planted at the order of 2500 stems per hectare. This initial dense stocking aimed to provide a final crop of 250 good sawlog trees per hectare, over a 40-year rotation. These densely stocked stands of variable vigour and form incurred high costs in the nursery, in establishment and in culling and pruning.

In 1957, with the prospect of extending the plantation area to approximately 80 000 ha, an improvement program was begun to breed a tree more suited to plantation management in WA. Mass selection in the limited areas of mature stands established within the State separated 54 plus trees. Selected trees were dominant or co-dominant in height with straight stems and healthy narrow crowns. The intensity of selection was in the order of 1 in 14 000 of trees planted for the average plus stem and 1 in 100 000 for phenotypes of the standard of the ideotype. Of this initial selection only 5 or 6 trees conformed to the ideotype for vigour and form.

A clonal seed orchard of 10 ha was established at Joondalup, in 1963 and 1964, by grafting the best 16 of these 54 selections. A clonal orchard was favoured to provide yields of improved seed for operations as soon as possible. Provision was made to test the breeding value of the selections by progeny testing.

The program developed features which made it unique among the various projects at that time. The emphasis on mature phenotypes provided too small a scope for selection in the restricted local stands of the species. To obtain sufficient numbers of straight, mature parents, agreement was made with other authorities in Australia and New Zealand to send a forester to Portugal for two years to select plus trees in the original stands of the provenance. Eighty-five parents were selected and introduced to WA as grafts (79), half-sib seed (62) and pollen (2). Scions and full-sib seed from these selections have been distributed to the other Australasian collaborators and forestry organizations in South Africa.

Half-sib progeny tests have shown that 47 per cent of the clones, selected in Portugal for dominance in vigour, maintained this attribute and produced heights and diameters superior to imported commercial seed lots, under WA conditions. Ninety per cent of the imported selections are better in stem straightness and apical dominance than the routine seed batch and all imports have transmitted improved quality in branch size and branch characteristics to their half-sib offspring.

The Joondalup orchard was enriched in 1966 by interplanting 54 new Portuguese clones. In 1974-75 the original 16 clones were thinned and culled on the basis of early progeny test information. A second clonal orchard using up to 96 clones selected in mature stands in Portugal and younger local stands was established in 1969-72. This has been thinned and culled, progressively, with progeny test information, to the best 30 to 45 clones. A second generation seed orchard of proven clones and recombinations from the first generation pollination and progeny testing program was planted at Manjimup in 1986-90.

Importation of parents from external sources provided for a most effective first generation program which yielded improvement over the commercial control in excess of 10 per cent for diameter and height, 44 per cent for stem straightness and 30 to 20 per cent for branch size and angle. Yield trials from seed of the unculled Joondalup seed orchard show increased volume production of 36 per cent, 31 per cent improvement in stem straightness and some 7 per cent improvement in limb size.

The improvement program required measures to counter bird damage to the seed crop. Orchard location, scare guns and early cone collections were employed to avoid damage from black cockatoos and allow cone crops to be harvested. Efforts were concentrated on a full-sib, controlled pollination program for progeny testing as a result of the unavailability of half-sib seed because of cockatoo damage to cones on the parent tree. All controlled pollination was carried out on ramets in a scion arboretum in which bird damage to developing cones was avoided by covering the conelets with a calico bag in the second year of development.

Some 195 ha of progeny tests have been established to test the genotype of clones and determine which would remain in the orchards and to provide new genetic combinations for second generation selection. Forty-five local clones and 77 imported clones were evaluated against three or more tester pollens. Sixty-eight trials are involved and these include 65 families from a 5-tester system used in South Africa.

Each of 122 first generation parents found to be acceptable from the tester trials was crossed to provide random pair matings for second generation selection. Pollens from nine superior genotypes imported from South Africa were included in this random crossing program.

Thorough trial design, replication and maintenance has provided effective improvement of the species. This is partly due to raising all full-sib plants for trials in tubes and removing variation owing to nursery conditions or field establishment. Most trials incorporate a commercial routine family to evaluate improvement obtained. Linking of trials with standard families has proved a most efficient procedure for comparing all data. Results are now obtained from a computerized database and family or parental data is immediately integrated in the locally developed Breeding Information System for management of WA tree breeding.

Interactions between genotypes and site were relatively common for height and diameter data but were either of a low level or of no significance. Genotype-site interaction is not considered to be important from the point of view of selection of families or parents. Because fertilization is standard practice in commercial operations, several specially designed trials have evaluated the impact of interactions between fertilizer and genotype.

Since 1971 all seed for the 13 000 ha of plantation extension of the species in the State has been obtained from the orchards. Realization of the promised improvement and the opportunity to drastically reduce initial stocking levels and subsequent culling and pruning costs has favoured continuation of the plantation program in the presence of rising costs and new land use pressures. The Joondalup orchard was the major supplier up to 1976 when it was superseded by the Mullaloo orchard. The Mullaloo orchard should meet all requirements until 1995 when seed will become available from the second generation orchard at Manjimup. Supply of improved seed now exceeds demand in WA and a surplus is available for export.

Parents included in the Manjimup orchard were largely selected on the basis of the best individuals found in the best families in progeny tests. Wood density was also included as a selection criteria. Heritability and genetic correlations obtained from the first stage of the program indicate that at least a further 16 per cent improvement in tree vigour is possible in a second stage program using index selection procedures. This further improvement would be obtained while maintaining the high standard for stem form achieved in the first stage.

However, economics no longer favours *Pinus pinaster* plantation practice in WA and it is not expected that the planted area will be extended. No further development of the second generation program is anticipated as current orchards should adequately meet perceived future needs for the species.

INTRODUCTION

Rationale for the Program

Pinus pinaster Ait., the maritime pine of southern and south-western Europe, was introduced into Western Australia (WA) in 1896 with the objective of establishing softwood plantations on undeveloped coastal plain sands in the south-west of the State. Extensive trials have since confirmed that the pine is the most suited for afforestation of some 80 000 ha of marginal soils considered for wood plantation establishment. In 1990, the total area of the species planted in WA was about 30 000 ha.

The first imports of seed were through French suppliers and predominantly were of seed collected from the Landes region in that country. Early growth, however, proved the advantages of the Portuguese provenance (Perry 1940, 1949) and, since 1940, all seed imported for plantation extension was collected in the Forest of Leiria, Portugal.

The general vigour of the Portuguese provenance, grown with the aid of fertilizer, was acceptable on the coastal sands but stem straightness, apical dominance, branch size and angle, crown shape and width and, to a lesser extent, variability in stem vigour in the population were unsatisfactory for effective plantation management (Fig. 1).

The ideal tree (ideotype) for use in WA should be healthy with good vigour for the marginal sites concerned, with a straight bole section and small, flat angled branches to favour small knot size. It should have a narrow symmetrical crown to minimize rainfall interception.

Assessment of these early stands of Portuguese origin showed that less than 13 per cent of seedlings planted developed to the acceptable vigour and form required in a managed final crop. Only 2 per cent of the population produced the ideal or the most desirable plantation tree (Hopkins 1960a).

To provide a reasonable final crop selection to meet the management objective for a final crop of 250 stems per hectare (stems ha^{-1}) over a 40-year rotation required the planting of about 2500 stems ha^{-1}. Resultant establishment and thinning costs were high and a large volume of poor quality logs would have to be placed on the market in order to obtain the desirable final crop saw logs.

Wide spacing is essential to effective management on the marginal soils owing to limited soil water availability (Butcher 1977b). This accentuated the importance of branch size, as the high cost of pruning large branches to obtain acceptable saw log quality was a major concern of management.

A breeding program was begun in WA in 1957 to ameliorate defects in *P. pinaster* for plantation wood production (Hopkins 1969). The priority was to improve stem straightness while maintaining dominant vigour. Reducing branch angle and branch size were secondary requirements.

Since 1957 three seed orchards and over 195 ha of progeny tests have been established. All seed of the species used in plantations since 1971 (approximately 13 000 ha) has been of seed orchard origin. Although internal reports have been available locally, the details of the program have not been published and it is timely to document the progress and to review the achievements of the program.

The program is reviewed in two parts to cover two development phases. The initial phase (The First Generation Program) used plus trees to provide improved seed from clonal orchards culled on the basis of progeny tests. The second phase (The Second Generation Program), which continues, uses genetically proven material and new families (Fig. 2). These have resulted from controlled mating and progeny testing. Whereas the selection emphasis in the first phase was on good stem form and vigour, selection in the second stage considers refinements such as branching and wood density to more directly meet the commercial requirement.

This paper describes the key activities (illustrated in Fig. 2) in the section entitled BREEDING PROCEDURES which includes chapters on Selection of Plus Trees, Vegetative Propagation, Controlled Pollination, Seed Production and Progeny Testing. Interpretation of trial results is detailed in EVALUATION AND SIGNIFICANCE OF THE TESTING PROGRAM. Improvement gains are reviewed in the section on RESULTS AND IMPROVEMENT OBTAINED. The final section, the BREEDING PLAN, outlines activity in the second generation program and summarizes the overall program.

Figure 1. Extremes of the range of tree form present in unimproved plantations of Portuguese origin in Western Australia.

BREEDING PROCEDURES

Objectives of the Program

The *P. pinaster* improvement program had two major objectives.

First, to improve stem quality in the population to allow wider plantation spacings and lower establishment and tending costs. Secondly, to increase the volume of the stand that could be commercially utilized.

Development of the Program

Introduction

To implement the program, a breeding centre was attached to the local forestry office at Wanneroo (latitude 31°45'S, longitude 115°48'E), approximately 27 km north of Perth. Office, laboratory, nursery and glasshouse facilities were established and a site for a scion arboretum was available some 10 km east of the forestry office.

Early procedures were based on mass selection within established plantations and were modelled upon advanced programs for southern pines in Queensland (Shepherd 1977) and North Carolina. Extended visits to Queensland were made by Hopkins in 1959 and Perry in 1963 to learn the basic practices adopted. Selection, propagation, orchard design and most other aspects of the WA program were strongly influenced by this experience.

Several factors, particularly the age of parents, bird damage and the extreme care in establishment, led to certain aspects of development that are unique to the program. This unique aspect is readily appreciated when the program is compared with early French improvement of the Landes provenance of the species (Alazard 1982). In France a wide range of local plus trees, progeny testing with half-sib material and field grafting to establish orchards greatly simplified and accelerated the improvement procedure.

Importing Parents - In the 1960s, in the absence of current knowledge of juvenile-mature correlations for desirable breeding traits (Gill 1987), it was decided that only proven, mature (final crop) trees would be considered as parents. This requirement for trees to be mature to be eligible for selection and the restricted areas of older, local plantations of Leirian provenance resulted in intensive efforts to obtain suitable parents from the original stands of the provenance in Portugal (Perry and Hopkins 1967). Selection, propagation and testing of these imported parents (Fig. 3) were vital to the program.

Bird Damage - Depredations of the local white-tailed black cockatoos (*Calyptorhynchus baudini*) in WA severely damage both developing and mature cones in the plantations and required compensatory moves in the program. The opportunity to collect seed from the mature plus trees was limited and progeny testing through using half-sib (one parent only defined) material was not employed for local tree evaluation. This placed the emphasis of progeny testing on controlled pollination which, again because of the cockatoo damage, had to be conducted under protection in a scion arboretum rather than on the original parent tree (ortet). The potential for cockatoo damage was also a major factor considered in the location, design and management of seed orchards.

Tubed Stock - The scarcity of controlled pollinated seed and problems with the reliability of establishment of the species on the infertile sands favoured the use of tubed stock with a well developed root system for progeny testing. This practice provided high survival and minimized seedling variation owing to nursery and establishment procedures. Grafting onto specially prepared potted stock, instead of direct grafting onto established seedlings in the field, as in France, was similarly used to overcome establishment problems in clonal orchards.

The Portuguese provenance of the species can be difficult to establish and improvement in nursery procedures, seed handling (Hopkins 1971) and silviculture (Butcher 1979) was essential for optimum use of expensive seed. This work was integrated into the breeding program.

Selection of Parent Trees

Initial Selections of Local Trees

A search for plus phenotypes was initiated in 1957 immediately following the decision to establish a tree breeding program. Trees were not considered as breeding parents unless they had reached a minimum age of 30 years. At this age they fully expressed the genotype for the site factors. This constraint restricted the area of the search to approximately 400 ha of mature plantation.

Selection Criteria - To aid selection a subjective system of scoring points for important features was developed. Marks were awarded for major attributes on a 5 point system as follows:

(1) Bole	5 (best) to 1 (worst)
(2) Vigour	5 (best) to 1 (worst)
(3) Branching	5 (best) to 1 (worst)
(4) Crown	5 (best) to 1 (worst)

The perfect tree would receive a total of 20 marks.

Certain factors are relative to site and comparison was made against a base population for the location of each prospective parent. To evaluate vigour, the height and diameter of an individual were compared visually with all trees of comparable site within a radius of 22 m. Branch size was also estimated relative to the girth of the tree and those immediately surrounding it.

The four factors were evaluated according to several criteria:

1. **Bole.** To secure full marks for this factor the bole had to be straight, round in section, vertical and to

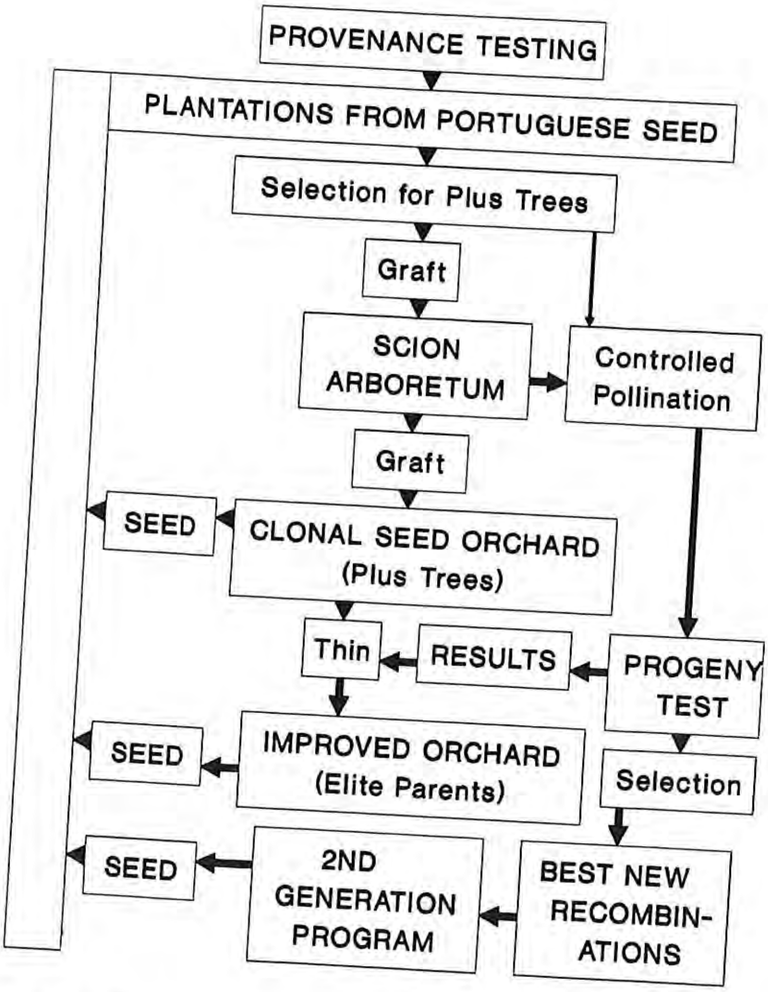

Figure 2. Diagram showing the basic approach used in the P. pinaster *improvement program.*

carry through the crown straight and unbroken to the growing shoot. There should not be swellings at the branch whorls and no kinks between whorls.

2. **Vigour.** This factor was judged by both total height and girth at breast height (g.b.h.). To receive full marks a tree had to be as tall as, or preferably taller, and its g.b.h. greater than any tree within a radius of 22 m. Vigour is such a vital trait in breeding and it was desirable to have all plus trees score 5 marks for this trait. In practice this was not possible, as generally the form of very vigorous trees scored poorly. Most plus trees selected scored four marks for this factor.
3. **Branching.** The branches of the ideal tree had to be small in size, few in number and grow out at right angles to the bole. Trees of this type were not found. The branches of trees in the Leirian race are almost invariably carried at a narrow acute angle to the stem, particularly during the first 20 years of the life of the tree. The angle tends to become wider in the upper crown as the tree becomes older and height increment becomes shorter.
4. **Crown.** The crown had to be conical in shape, well balanced, symmetrical, healthy and well clothed with needles. There should be no tendency for the crown to flatten out before 30 years of age. It was often difficult to evaluate crown shape as many crowns were misshapen owing to pressure for space by adjoining trees.

Leiria provenance - Five trees with exceptional qualities (E2, E5, E40, E41, E53) were immediately identified by local workers experienced in tree selection for pruning and thinning. The remainder were collected by ensuring that at least the best tree in any compartment (20 ha) was marked for further consideration. This approximated a selection intensity of 1 in 27 500.

Insufficient quality trees were obtained to provide a sample size (16 to 30) sufficient to allow future culling and prevent excessive inbreeding in a seed orchard. Therefore, to raise the selection number to 16 favoured clones, the minimum deemed necessary from studying other tree breeding schemes, stands older than 23 years were included in the search. Fifty-four plus trees of Leirian origin were selected for cloning and evaluation during this period 1957-1960. These trees were selected at an intensity of the order of 1 in 14 000.

Other Provenances - Selections were also made in some of the best mature local plantations of other provenances (Landes and Corsican) and several plus phenotypes representing these races of the species were located. While it was never intended to use these trees in orchards, grafts from seven plus stems of Landes origin and four Corsican were established in the Neaves Road scion arboretum in 1962 for future study and hybrid crossing trials.

Selections in Portugal

Arrangements were made with Australian and New Zealand authorities to select further plus stems from mature stands in Portugal. This overcame the inadequacy of the local selections and provided a safe base of mature parent trees for future breeding populations. Under the terms of the agreement costs of selection and collection work in Portugal were shared on the understanding that the clone material would be distributed to all participants (Perry and Hopkins 1967).

Figure 3. One of the 86 plus trees selected in Portugal and transferred to Australia by seed, scions and, in two instances, by pollen.

Special Selection Criteria - In Portugal only the better stands were evaluated for selection purposes and these ranged in age from 30 to 136 years. They were even-aged and the result of centuries of management. The majority of selected trees fell within the 50 to 80 year age interval (Fig. 3). A more detailed scoring system based on a total of 100 points accompanied this selection (Table 1). A ranking of the trees on this basis is contained in Appendix I.

The prime objective in the search to improve stem form, favoured trees in which the bole was straight, of circular cross section and with pronounced leader dominance. Only trees of dominant or codominant vigour were included in the final selection.

Verticality and lean were gauged against a plumb bob line. Vigour was assessed by comparison with the height and girth of the largest trees within a 22 m radius of the possible plus phenotype. Measurements for spiral grain were made on the boles and 12 mm cores were obtained from each tree for testing the wood properties. Detailed photographs were taken of each tree.

It is estimated that the selection intensity involved was of the order of one plus phenotype per 250 000 trees.

Results - This program (Perry and Hopkins 1967) provided a further 85 phenotypes for consideration: 79 were successfully introduced as clonal material, 62 from half-sib seed, and two from imported pollen.

At the time of assessment half of the Portuguese selections were considered to be of a standard comparable to that of the best five selected in WA. It remained to be proven that dominant genotypes in Portugal would also be dominants under WA plantation conditions.

Secondary Local Selection

Additional selections in maturing local stands were conducted in the 1970s, particularly between 1972 and 1974, to increase the number of local selections from 51 to 86.

Special Selection Criteria - Use was made of the procedure of comparison trees employed in the improvement program for *Pinus radiata* (Pederick 1967; Eldridge 1977). Measurements were made of diameter and bark thickness at 1.3 and 4.5 m height, total height and height to live crown for both the candidate plus tree and the nine associated final crop trees on the similar microsite. Points were also awarded to the candidate phenotype for straightness, branch thickness, branch angle, crown symmetry and health and presence or absence of cones on the tree. Population means and the standard deviation were calculated and trees were rated on the number of standard deviations by which the candidate exceeded the population mean of the final crop trees.

Three plus trees selected in South Australian plantations were also included in the local program.

Vegetative Propagation

Introduction

Obvious difficulties in forest tree breeding are associated with :

1. manipulating controlled pollinations in the crowns of the selected, tall, mature plus trees; and
2. delayed maturity in trees and the relatively long time intervals required to produce commercial quantities of seed from improved offspring or evaluate the parents in progeny tests.

These difficulties were minimized by using vegetative reproduction to mass produce and relocate clonal material for easy pollination (at an accessible location and at a manageable height) and for early commercial seed yields (from clonal orchards).

Direct rooting procedures such as cuttings and air layering of shoots have little success in mature *P. pinaster* and bottle grafts onto potted stocks (Fig. 4) were initially used for vegetative propagation. The rather cumbersome bottle graft was considered to be more effective with aged material from the original ortet. From 1962 experience and the availability of small, vigorous scions from scion arboreta replaced bottle grafting with tip cleft grafting. Tip grafting has since been the predominant procedure for vegetative propagation.

Figure 4. Early bottle grafts held in a temporary shade house.

Grafting Procedures

Stock Plants - Field grafting has not been used in WA for *P. pinaster*, because of the inconvenience and variability associated with the practice. Stocks for grafting were specially prepared and have been found to be a key to a successful program.

Metal cans 23 cm deep and 18 cm diameter were used to raise the stocks. These were painted with bituminous paint to prolong the life of the can . The can was pierced on the bottom edge to provide for drainage. Dominant seedlings from seed sown in open nursery lines in August were potted in the cans in the following July. Initially a soil mix consisting of 4 parts loamy sand, 1 part clay loam and 1 part shredded, well rotted, cow manure was used. The seedlings were grown in the nursery, in full sunlight, until required for grafting.

The objective was to produce a strong, vigorous stock of about 40 to 45 cm height at time of grafting. This involved considerable hand watering and application of liquid fertilizer to boost growth. Later, for the main grafting program, a soil mix of 3 parts sand, 1 part loam and 1 part peat moss was developed. This accommodated watering by overhead sprinkler and fertilizing with liquid fertilizer (23 per cent N, 4 per cent P, 10 per cent K) as required. The availability of glasshouse facilities allowed the stocks to be forced into flushing whenever necessary. At the peak of the program of orchard establishment from 1962 to 1972 (Table 2) some 5000 pots (grafted or in preparation) could be present at the breeding centre (Fig. 5). Cans were reused and had an operational life of approximately four years.

All potting materials were fumigated with methyl bromide before use and the glasshouse, shade house and free-standing area were treated with formalin once a year. Current facilities have all stock off ground on benchs and a foot-cleaning tray containing a disinfectant, to prevent the introduction of fungi to the area.

Local Scions - Shoots for grafting were initially obtained by climbing the plus tree in spring. Later, all scions were obtained from ramets in the scion arboreta.

Scions were selected as near to the tip of the mature tree as possible because shoots from the lower crown do not graft well. Extensive testing over several years showed the most suitable scion material to be the leading vegetative shoots of first and second order branches and also the tips of branches which produce the male inflorescences (Fig. 6). The latter grafted equally well either before or after the pollen had shed. Shoots from grafts maintained in a vigorous condition in the scion arboretum grafted readily and were easier to match to the stock sizes available. This greatly facilitated the grafting process and provided high survival percentages (Table 3). A much longer (15 cm) scion was required for bottle grafting than the smaller (3 cm) scions which were readily available for tip grafting.

TABLE 1

Scoring system used to allocate priorities to phenotypes selected in Portugal.

Bole. Perfect score			100
Overall straightness. Maximum			50
Very slight bow	deduct	5	
SLIGHT BOW	DEDUCT	10	
VERY SLIGHT BUTT SWEEP	DEDUCT	10	
Slight butt sweep	deduct	15	
Very slight pistol butt	deduct	10	
Slight pistol butt	deduct	15	
Defects in excess of above	reject		
Inter-whorl straightness. Maximum			5
One very slight kink	deduct	2.5	
Two very slight kinks	deduct	5	
Defects in excess of above	reject		
Verticality			20
One degree of lean accepted as vertical			
For every degree of lean in excess of one	deduct	5	
More than 5 degree lean	reject		
Circularity. Maximum			5
Boles not circular in section...	reject		
Nodal swellings. Maximum			15
Very slight nodal swellings	deduct	5	
Slight nodal swellings	deduct	10	
Leader dominance. Maximum			5
Trees in which the leading shoot does not persist through the crown.	reject		
Vigour. Maximum			100
Predominant tree	score	95	
Dominant tree	score	85	
Codominant tree	score	75	
Crown. Maximum			50
The crown required was symmetrical, compact and healthy. No deduction made when defect was obviously due to environmental factors.			
Branching. Maximum score			50
All Portuguese trees were high pruned and no assessment was possible.			

The influence of vigour of scions on grafting success is shown in Table 3. Survival percentage varied from 52 per cent with scions from 32-year-old plus trees to 83 per cent with material from rapidly growing ramets in the scion arboreta. There is also a definite genotypic variation in grafting. Some clones proved to be quite difficult to graft (Table 4), even when scions were obtained promptly from vigorous, healthy buds in the scion arboreta (Table 5).

Following collection scions were placed in polythene bags, sealed and stored in the refrigerator for up to a week before grafting. Usually they were grafted within two days of collection.

By 1962, the majority of scion material was being obtained from the scion arboretum. This greatly reduced times for scion collecting and handling and improved grafting results.

Importing Scions - The decision to import scions of plus trees selected in mature stands in Portugal required:

1. approval for importation from quarantine officials;
2. imported scions to be fumigated with methyl bromide, at the rate of 1.0 kg per 30 m^3 , for 2 hours at 21°C;
3. the use of the minimum number of scions, to guarantee successful clonal transmission;
4. scions be dipped in a fungicide (Zineb) prior to grafting; and

TABLE 2
Grafting program for *Pinus pinaster* at Wanneroo.

YEAR	GRAFTS ATTEMPTED	RAMETS PRODUCED	PERCENTAGE SUCCESS	NO. OF CLONES
1958	124	91	75	6
1959	352	178	52	11
1960	535	69	20	5
1961	694	427	62	17
1962	2 000	1 541	77	19
1963	1 596	1 312	82	16
1964	1 519	86	6	53
1965	1 820	584	32	50
1966	551	512	93	10
1967	351	217	62	17
1968	1 026	895	87	54
1969	3 044	2 712	90	79
1970	4 614	3 300	72	94
1971	1 925	1 294	67	92
1972	404	114	28	19
1973	114	95	83	9
1984	458	178	39	35
1985	934	523	57	116
1986	1 795	861	48	109
1987	2 763	2 648	96	155
1988	615	538	87	41

Figure 5. The glasshouse and developing stocks for grafting at the Wanneroo Breeding Centre.

TABLE 3
Variation in grafting survival in 1962 with scions taken from young ramets in the scion arboretum or directly from mature plus trees of varying age in the field.

AGE OF PLUS TREE OR RAMET	NO. OF GRAFTS COMPLETED	NO. OF GRAFTS SURVIVED	SURVIVAL (%)
3 to 4 years (Scion Arboretum)	920	762	83
21 years (Planted 1941)	624	420	67
32 years (Planted 1931)	558	292	52

TABLE 4
Results obtained in autumn in 1963 demonstrating the infuence of season on grafting survival of different genotypes.

PLUS TREE	SOURCE OF SCIONS	NO. OF GRAFTS	NO. OF SURVIVORS
E50	34 year old ortet	25	3 (12%)
E49	34 year old ortet	25	3 (12%)
E53	34 year old ortet	25	5 (20%)
E41	4 year old ramet	25	17 (68%)
E02	4 year old ramet	25	24 (96%)
E14	4 year old ramet	25	22 (88%)
E40	4 year old ramet	25	12 (48%)
E05	4 year old ramet	25	18 (72%)
E28	4 year old ramet	25	1 (4%)

5. successful grafts be maintained for 12 months in an insect-proof glasshouse with monthly inspections from a pathologist and an entomologist.

Grafting would have to be in both autumn and spring to guarantee success within the two years proposed for the visit of an officer to Portugal.

Grafting Techniques - Several grafting techniques were used.

Bottle grafts - In 1958 and 1959 bottle grafting and side veneer techniques were used. Following manipulation the tube was filled with water and the graft placed in a temporary shade house (Fig. 4). Survival could be assessed within 6 weeks when the bottle was removed, the excess scion severed and the cut closed with mastic. In these early grafts the tie was bound with polythene tape and waterproofed with grafting mastic.

The procedure proved effective and successful takes of approximately 60 per cent (Table 2) were obtained under rather primitive conditions for grafting, scion storage and after-care. Scions were usually large, of limited vigour and in the initial years (1957-1960) stock preparation and shade facilities were limited. These grafts required regular spraying with white oil and malathion to control infestations of woolly aphid (*Pineus pini*) which flourished under the partial shade and humidity. The infestations were of nuisance value only but required attention throughout the whole program.

Tip grafts - With the favourable conditions of developed root stocks, scions from the arboreta, glasshouse facilities and trained staff, tip cleft grafting (Fig. 7) was introduced in 1961. Grafting was carried out with a surgeon's scalpel (No.4) with replaceable blades (No. 24) and 1.2 cm wide polythene tape for binding. Mastic was not required.

This proved to be superior to the bottle graft and apart from some of the imported scions from Portugal, has been the only procedure for grafting used since. It is quick, neat and involves less after-care.

Importation trials - In October 1964 a grafting trial was conducted to develop the most favourable technique for importing scions. Factors considered were the impact of fumigation, type of graft, storage time and storage procedure.

TABLE 5

Grafting in 1962 showing improved survival in the glasshouse as opposed to holding in a shadehouse.

PLUS TREE NO.	DATE OF GRAFT	GLASSHOUSE		SHADEHOUSE		AGE OF RAMET OR TREE
		NO. GRAFTED	SURVIVED (%)	NO. GRAFTED	SURVIVED (%)	
E14	23 Aug	122	94	12	58	R 3-4 years
E15	3 Sep	118	90	12	50	R 3-4 years
E28	4 Sep	113	76	12	58	R 3-4 years
E40	6 Sep	105	82	24	71	R 3-4 years
E41	11 Sep	89	93	48	69	R 3-4 years
E47	17 Sep	50	94	80	66	21 years
E31	18 Sep	41	56	80	79	21 years
E19	19 Sep	38	63	80	52	21 years
E45	25 Sep	50	78	80	39	21 years
E46	25 Sep	50	94	75	68	21 years
E49	13 Sep	60	67	70	57	33 years
E33	4 Oct	60	90	67	27	33 years
E50	8 Oct	50	86	71	31	33 years
E53	9 Oct	48	48	72	37	33 years
Total		1 004	82%	783	53%	

Figure 6. Male strobili in the process of shedding pollen.

Results (Hopkins 1966) indicated that scions stored without added moisture and grafted by the bottle technique should have most chance of success.

Season - Early testing showed that the best time to graft was spring, just as the terminal buds had started to enlarge. Grafts were sheltered in partial shade conditions until the following autumn when the survivors were placed in full sunlight to harden. They were planted out in the field in June or July some 9 to 10 months after grafting.

Grafting normally began in the middle of August and was completed by mid October. Results to assess an optimum time for grafting were obtained within the initial bottle graft program. However, with improved stocks, scions, shade house and glasshouse facilities, time of grafting within a season was not found to be critical.

Trials in 1963 (Table 4) demonstrated that autumn grafting (March and April) could be satisfactory with material from the scion arboretum.

Survival was obtained with imported material from both dormant scions (autumn) and scions in flush (spring). For grafting in either season root stocks were flushed in the glasshouse.

Figure 7. Procedure for tip grafting showing the cut scion and stock (left), the graft bound by polythene tape (centre) and the successful graft (right).

Dormant buds grafted in the southern spring recommenced development without the cold exposure of a winter. Growth was of the long bud or lammas type (Fig. 8) and needles were not developed until after the following winter.

After-care - Grafted plants were placed in the glasshouse for about six weeks until success was evident. To cool the glasshouse a frame was erected over it and hessian blinds (Fig. 5) were drawn as required. Survivors were then transferred to a shade house until March when they were placed in full sunlight to harden prior to planting.

The benefits of using the glasshouse for after-care are demonstrated in Table 5. Eighty-two per cent success was obtained using the glasshouse compared with 53 per cent survival in the shade house.

Throughout the summer and winter periods the potted grafts were watered regularly and fertilized. This was an expensive procedure which was later ameliorated through the use of peat-sand potting mixes which allowed sprinkler watering.

Insects and Fungi - The only insect or fungal problems experienced concerned infestations of woolly aphid and the occasional development of needle cast fungi. These were favoured by the shady, humid, after-care conditions but were not seen to have an adverse effect on the developing plants. The leaf cast ceased to become a problem once the new needles emerged and the aphid was controlled by fortnightly sprays of white oil and malathion.

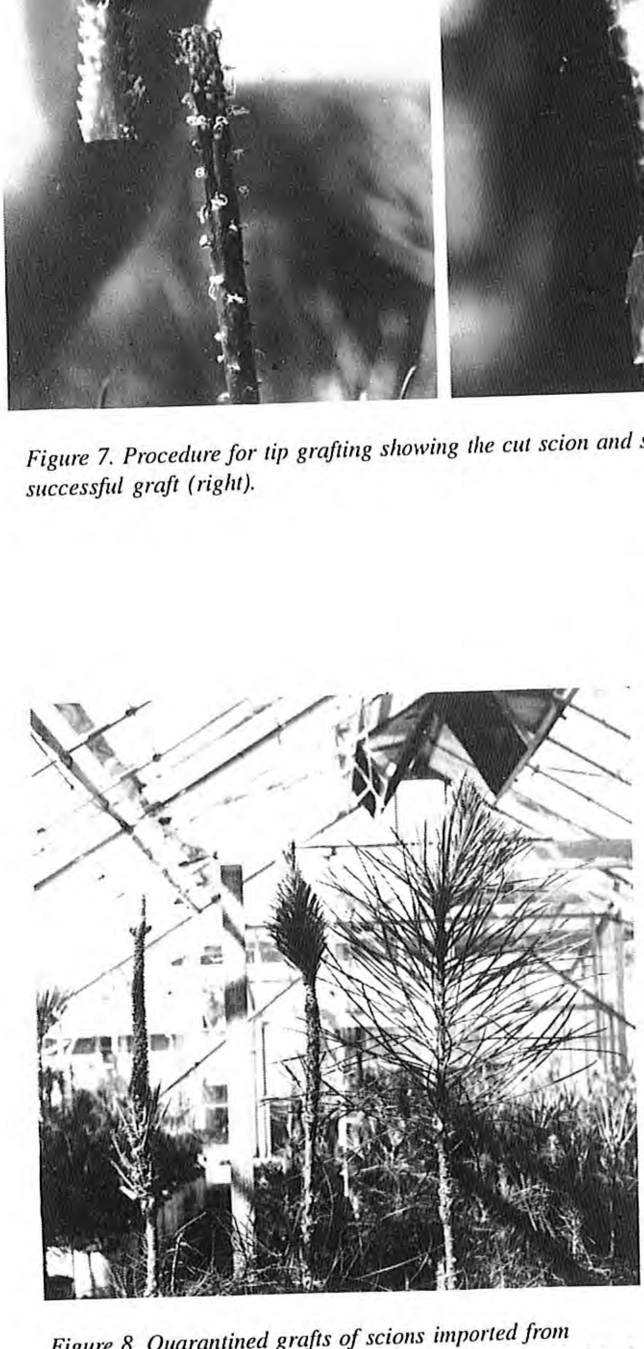

Figure 8. Quarantined grafts of scions imported from Portugal in September (left) and May (right). Scions picked at the end of the northern summer (September) developed long bud or lammas growth.

Results - Results of the grafting program are summarized in Table 2.

Early grafting from 1958 to 1961 was used to develop techniques and initiate the scion arboretum. The output was increased from 1962 and 1963 to establish the Joondalup seed orchard. In 1964 and 1965 the program concentrated on imported material which was budded in 1966 and 1967. Grafting was restricted in these latter years as available scions were distributed to South Australia, Victoria, the Australian Capital Territory and New Zealand.

The propagation program increased again during the period 1968 to 1971 to establish the Mullaloo seed orchard. A peak input of 4598 grafts with 73 per cent success was achieved in 1970.

Grafting was minimal from 1972 to 1984 and was aimed at multiplying imported clones with limited ramets and duplication of clones on at least two sites. In recent cloning for the establishment of the second generation orchard at Manjimup and the Hopkins Road clone bank it was necessary to graft in late October to December. Survival percentages were lower than usual, ranging from 40 to 60 per cent. This was partly the result of some inexperienced grafters and inadequate after-care. The program in 1987, however, was the third largest and with 96 per cent success, provided the best results for any year of grafting.

Scion material imported (Perry and Hopkins 1967) varied in age from 30 years to 186 years. A total of 3116 grafts were made with an overall survival of 17 per cent. Table 6 illustrates the seasonal variation. Of 86 clones grafted 79 were established as one or more grafts.

The first importation of 1529 scions provided only 6 per cent take. Separate importations of this material to Canberra and New Zealand failed completely on grafting. This initial batch of scions was collected in the northern hemisphere autumn and grafted, one-third as bottle and two-thirds as tip grafts, in September in the southern spring (Appendix III). All bottle grafts failed, even though the preliminary trial suggested that this may be more effective than the tip procedure under the conditions. This early shipment was packed in spagnum moss which was slightly moistened, a procedure shown to be most unfavourable in the trial. It is believed that the moist storage was the major cause of the failure of grafts in this first attempt.

The virtually complete failure of the imported batches in September 1964 (Table 6) seriously reduced the overall survival percentage. At this stage it was agreed by the institutions participating in the introduction program to concentrate all further grafting in WA. As the bottle technique had not proven an advantage over the tip technique, all further grafts were of the simpler, more rapid tip type. Results for subsequent tip grafting, even when very large scions poorly matched the root stocks, provided survival values averaging 30 per cent.

Certain clones which failed to take in WA were grafted successfully in Portugal. An attempt was made to import these established grafts. The roots were washed clear of soil prior to air-freighting and they were fumigated with methyl bromide on arrival in Perth. None survived.

In 1972 investigations were made into the feasibility of propagating the 5-year-old progeny of controlled crosses by cuttings, girdles and air layers. Direct cuttings were a complete failure owing to ineffective control of humidity in the setting beds. Sixty per cent of the air layers formed roots and subsequently developed strong shoots. Grafting was by far the simplest procedure for vegetative propagation of mature material for the species.

Following work in the eastern States and New Zealand to mass produce superior cuttings of *P. radiata* (Clarke and Slee 1984) another local study was commenced in 1983. Francelet (1979) indicated that success in the procedure for *P. pinaster* required the use of very young seedling material.

Seed from each of 30 superior families produced in the crossing program was sown in tubes in December 1983. In July 1984 the tips were removed from each seedling and set in prepared cutting beds. Further cuttings were taken from the multiple shoots developed on the decapitated seedling in November 1984. The process was completed in April 1985 and successful cuttings were planted out at 1.5 m spacing on a special site at Gnangara nursery. Other cuttings were established in the Hopkins Road clone bank. Ortet and ramet cuttings were maintained in very large containers in the nursery at Wanneroo and used for serial cutting propagation. The progeny trial YS68 planted at Busselton in 1991 used rooted cuttings originating from these potted ortets. Procedures have not been developed further and cuttings have not played a significant role in the overall breeding program.

General - *Pinus pinaster* must be assessed as one of the species most amenable to grafting. After some 20 000 successful grafts, with the earliest now in excess of 30 years of age, not one failure owing to stock-scion incompatibility has been observed in the field. Grafts of the species mature in a healthy condition and are wind stable.

The Scion Arboretum

Bringing together of all clonal material to be used in the breeding program on a readily accessible site was important to the operational plan. The site for the Neaves Road Scion Arboretum was selected in 1958 and the first grafts planted out in 1959. The site is of good soil quality, flat and within 10 km by all-weather access road to the Wanneroo centre.

The objective of the arboretum was to establish 10 grafts (ramets) for each clone. This varied somewhat, being dependent on availability of grafts. Grafts were planted in rows at a spacing of 3 m x 3 m. The area was fenced, maintained weed free until the pines controlled the site, and fertilized with nitrogen-phosphorus fertilizer at regular intervals. The area of the arboretum is 2 ha and it contains some 1777 ramets (all permanently labelled) of 123 clones of *P. pinaster* (Table 7 and Fig. 9).

TABLE 6

Survival values obtained from direct grafting of scions imported from Portugal.

GRAFTING PERIOD	NO. GRAFTED	SURVIVAL (%)	GRAFT TYPE
Sep 1964	1529	5.6	Bottle and tip
Mar 1965	892	29.6	Bottle and tip
Apr 1965	349	10.0	Bottle and tip
May 1965	211	39.3	Tip only
Sep 1965	135	38.6	Tip only
Total	3116	16.6	

TABLE 7

Progress of introduction of clones to the Neaves Road Scion Arboretum.

YEAR PLANTED	NO. OF CLONES	NO. OF RAMETS
1959	6	73
1960	11	178
1961	9	107
1962	33	584
1963	24	75
1964	13	64
1965	12	13
1966	77	433
1967	10	77
1968	16	142
1971	7	31

Figure 9. Two rows of 10 ramets from each of 2 clones in the Neaves Road Scion Arboretum in 1964.

Scions suitable for grafts were usually available within a year of grafting. Female flowers normally developed in the second or third year in the arboretum. Male strobili mature later and for initial work all pollen was collected from the ortet and stored for the next year.

The scion arboretum was also used for comparative studies of clonal development, flowering times and yield.

The original arboretum was completed in 1971 (Table 7). To minimize the use of high platforms and climbing on the taller ramets in the later pollination program, younger, smaller ramets in the developing seed orchards were used to supplement the arboretum for some crossing.

Small back-up arboreta were also established in Clover Block, Gnangara and in Wellbucket at Mundaring. These were purely security units to offset potential wildfire damage. All clones were located on at least two separate sites.

A new scion arboretum has been planted with clones from the second generation program, at Hopkins Road, to the north of the Wanneroo centre.

Controlled Pollination

Introduction

Female inflorescences of the Leirian provenance of *P. pinaster* are receptive to pollen from about the beginning of September to late September. The female floral buds can be distinguished from vegetative buds (Fig. 10) several weeks before they reach the receptive stage. Pollination is effective at any time during a 4- to 6-day period when the scales on the flowers are open.

Little growth is made by the cones in the first 12 months following pollination. The scales close and enlarge slightly and the colour changes from purple to brownish and then to green. Twelve months after pollination cones begin to enlarge rapidly and by the following September the seed is fully ripe.

Controlled pollination was vital to the improvement program owing to difficulties in obtaining half-sib seed from local plantations for progeny testing. It was facilitated by concentrating clonal material in the Neaves Road Scion Arboretum, close to the breeding station. Daily visits to the arboretum during the flowering season (September to October) provided for precise timing in enclosing female flowers (conelets) to prevent contamination from foreign pollen and in applying pollen. Work was carried out from the ground or low platforms which provided both ease and safety.

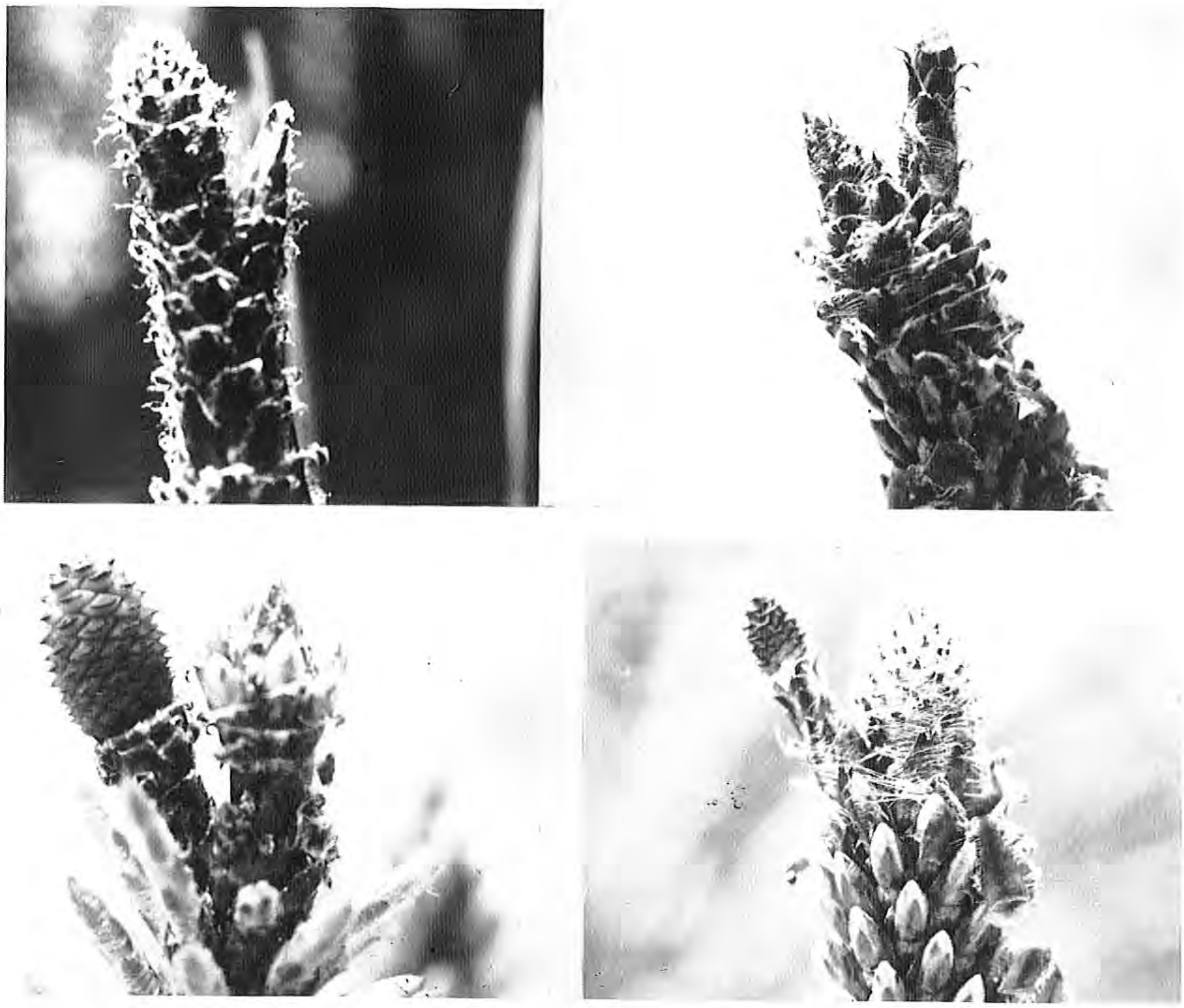

Figure 10. Early development of the female strobili.
Top left - Characteristically pointed female bud initial below the vegetative bud in early September.
Top right - Bracts around the female bud have parted and the tip of the strobili with closed, pink, ovuliferous scales is exposed.
Bottom right - The pink strobili is fully receptive with the open ovuliferous scales quite distinguishable. This stage lasts for 4-6 days.
Bottom left - The ovuliferous scales have closed and enlarged and the conelet changes colour from pink, to green, to brown (October - Novermber). It develops little further until the following spring.

Controlled pollination was used in the program to:

1. evaluate the genetic characteristics of the selected plus phenotypes and to ascertain their fitness to be included in commercial seed production ventures;
2. produce new families (genetic combinations) from the most promising phenotypes for selection in the second generation program of improvement.

Pollination Procedure

In practice, selected flower initials were isolated with viscine plastic sausage casings (30 cm circumference) to prevent external pollen contamination. These exclosures were attached prior to the appearance of any sign of the pink ovuliferous scales at the bud apex. The casing was tied tightly to the top of a supporting wooden splint, around a pad of cotton wool and a light wire cage was inserted to prevent shrinkage and damage to the buds (Fig. 11). The casing was tied again at the base around a pad of cotton wool and the splint secured to the branch at the bottom, ensuring rigidity. Enclosed flowers were watched carefully and the casings raised from time to time to avoid constriction and deformation of the elongating shoot.

Pollen was applied using a 10-mL hypodermic syringe with a No. 23 needle pushed through the casing. A light stream of pollen grains was directed over the flowers (Fig. 11). Normally the pollen scheduled for the cross was applied at least twice during the period that the scales were observed to be receptive. A 'write-on' aluminium tag bearing details of the reference number, the clone, pollen parent and date was attached to the stem or branch immediately below the pollinated flowers. Coverings were removed after the flower scales closed.

An initial estimate of the success of pollination was made by checking the size and colour of the fertilized conelets in November, three months after pollination. This estimate was confirmed in the following spring as the successfully fertilized conelets began to expand. At this stage a calico bag was placed over the developing cone to prevent bird damage (Figs 12 and 13).

Figure 11. Pollen application in the scion arboretum. The viscine exclosure used to exclude foreign pollen and its method of attachment are shown.

Pollen Handling

Whenever possible fresh pollen was used for pollination. However, this option was often precluded and pollen collected and stored in the previous year was essential to the program.

Collection - Pollen collections were made initially from pollen-bearing branchlets (Fig. 6) picked just prior to the strobili opening. They were washed under a tap of running water to remove any surface contamination and placed with the cut ends in water in jars in the laboratory. The jars were stood on sheets of brown paper and sheets of polythene were placed over the shoots to prevent contamination from airborne pollen.

Once shed the air-dried pollen was gathered and cleaned by passing it through a fine sieve containing 25 to 30 meshes per centimetre. Sieving removed all debris and, with drying, was essential to the free flow of the pollen through the nozzles of the applicator.

From 1966, the increasing quantities and origins of pollen required each year made it more convenient to collect pollen by placing viscine casings over the developing male strobili on branches in the field. Normally all strobili were enclosed before there was any pollen shed in the area but if there was any doubt of surface contamination, strobili were washed with a water spray prior to fixing the enclosure. Ripening and collection were carried out either on the tree or within the casing retained on the severed branch in the glasshouse.

Storage - Dried, sieved pollen was kept in test tubes with cotton wool stoppers and stored in desiccators over silica gel. To maintain viability it is essential that the pollen remains dry at a moisture content of 10 per cent or less.

Pollen stored in the desiccators in the cold chamber of a refrigerator has been maintained for several years at -14°C without any serious loss in viability. For safety, all stored pollen was divided and maintained at two separate centres (Wanneroo and Como). Pollen imported directly from Portugal (2 clones) and South Africa (9 clones) was stored for use in two seasons and incorporated effectively into the local program. Pollen of 20 local collections sent to South Africa in 1973 was also successfully incorporated into their crossing program.

Quarantine requirements for genotype introduction were successfully met by importing cleaned and dried pollen.

Testing - Pollen viability was usually tested by the Hanging Drop germination method (Franklin 1981). A drop of water on a microscope slide was dusted with pollen and the slide inverted, supported by glass rods, over distilled water in a petri dish. After 4 to 5 days the percentage of germinating pollen grains were counted under a microscope.

Figure 12. Expansion of the fertilized cone in the spring following pollination.

Figure 13. Successful pollinations covered by calico bags, prior to cone enlargement, to prevent bird damage.

TABLE 8

Variation in percentage of pollen germination for varying test conditions (main effects).

GERMINATION MEDIUM	GERMINATION TEMPERATURE
Agar = 30%	Bench (Room temp.)= 24%
Water = 23%	Incubator (25°c) = 28%
POLLEN SOURCE	NUTRIENT LEVEL
Clone 1 = 32%	0% Sucrose = 22%
Clone 2 = 20%	5% Sucrose = 27%
	10% Sucrose = 26%

TABLE 9

Pollinations carried out within the program.

YEAR OF POLLINATION	NO. OF FAMILIES PRODUCED	NO. OF MATERNAL PARENTS	NO. OF PATERNAL PARENTS	NO. OF CONES PRODUCED	SEED YIELD (kg)
		Full-sib.			
1961	16	11	2	80	0.27
1962	23	14	3	236	0.88
1963	20	12	3	350	1.50
1964	50	16	8	431	1.79
1965	66	34	11	828	4.18
1966	86	30	12	423	1.30
1967	47	30	13	209	0.49
1968	93	56	7	339	1.36
1969	109	70	8	542	1.71
1970	74	63	36	259	1.49
1971	84	67	42	438	2.16
1972	94	51	45	490	1.88
1973	32	24	24	177	0.64
1974	21	19	13	91	0.18
1975	26	16	14	158	0.32
1976	41	8	8	202	0.22
1977	10	7	5	57	0.06
1979	15	7	8	150	0.52
1980	5	4	2	18	0.06
		Half-sib.			
1965	16	16		-	7.64
1966	16	16		3395	13.08
1967	16	16		1355	6.24
1968	-	-		-	7.07
1969	16	16		694	3.70

\- Data not available.

Some early problems were associated with testing and in 1966 alternative procedures were examined. Viability was measured on agar or in distilled water, with or without two levels of added sucrose and either on the bench at room temperature or in an incubator at 25°C. Pollens from two clones were used and the trial ran for 5 days in November. Results (Table 8) were not conclusive but suggested:

1. germination in the agar medium may be superior to that in water;
2. germination may be superior in the incubator;
3. the addition of 5 per cent sucrose to the germination medium may be beneficial.

Local pollen was discarded after one year in storage and replaced with fresh material. Testing under these conditions was unnecessary. The imported pollen remained effective after 2 years storage.

The Pollination Strategy

The program used the following pollination techniques:

tester pollens
selfing (self fertilization)
pollen mixes
random pair matings
partial diallels

The first pollinations were carried out in 1961 (Table 9).

Tester Pollens - Initial crossing procedures during the period 1961 to 1964 applied four standard tester pollens to the 16 plus trees used in the first seed orchard. Pollens from genotypes (E2, E5, E40, E41) of expected high value, were used. The program was revised in 1964 when the NCII procedure (Zobel and Talbert 1984), a factorial crossing design, was adopted. Forty-five local and 77 imported clones (Appendix II) used as parents in the first phase of the program were pollinated with at least three tester pollens by 1970.

Standard crosses were included. The program produced five standard crosses in most years and at least two of these were used in each progeny trial to link results across trials and years.

Self-pollination - A major intention in the early program was to self all plus trees to provide the option for pure line breeding with future out-crossing. A total of 21 trees were successfully selfed (Appendix II) and progeny have been planted out in special trials for evaluation.

Pollen Mixes - In 1970 a pollen mix (EM) was used on 21 of the imported clones. The mix consisted of equal parts of pollen from the 16 local clones used in the Joondalup seed orchard. Pollen mixes have the advantage of testing for general combining ability (GCA) with a minimum number of crosses and were a popular means of testing in other tree breeding programs at that time. They are superior to open pollinated crosses for testing because the common pollen population is guaranteed and all potential paternal parents are of relevance to the program. Top crossing with pollen mixes is excellent for defining GCA but provides no information on specific combining ability (SCA). With one parent undefined it offers limited scope for new family selections. Locally it has only been used for yield studies. The seed available from the 1970 EM crosses was made available to New Zealand for evaluation of the Portuguese clones.

Random Pair Mating - In 1970, with the completion of the basic tester program for parent evaluation, random pair matings were begun in order to produce a diverse set of full-sib families for the second generation program. For this purpose the tester matings are inadequate owing to common parentage and problems of potential inbreeding depression.

A minimum of three sets (63 crosses) of random pairs were produced between the most favoured clones (Appendix II) to ensure that the dominant characteristics of each parent had adequate chance for expression. Pollens from nine superior trees in South Africa were included in this program.

Random pair mating commenced in 1970 and finished in 1974. A total of 228 matings were involved. Thirty-one matings were completed in 1970 and 86, 79 and 32 in 1971, 1972 and 1973, respectively.

Diallel Crosses - During the period 1976-1980 pollinations to suit a reciprocal crossing plan between 10 of the most promising clones (E29, E33, E41, E50, E77, E152, E154, E158, E164, E165) were carried out in the Mullaloo seed orchard. The partial diallel will provide detailed genetic information for the species in WA.

The Pollination Program

Initially, the procedure was to pollinate 12 female flowers for an outcross and 20 flowers for selfing with the aim of providing 150 seedlings for progeny evaluation. This was later reduced to 6 to 10 flowers per desired mating, depending on the knowledge of previous success with the clone and the availability of female strobili.

The Wanneroo breeding facilities concentrated on grafting up to 1965. Once the first seed orchard was completed the emphasis was directed to the pollination and testing program to screen all parents used in orchard establishment.

The maximum number of pollinations per year was set at 1000. The program developed from approximately 500 in 1964 to 900 manipulations in 1971 (Tables 9 and 10, Fig. 14). In 1973 pollen collected from the first two individuals from outstanding second generation families S57 (E19xE29) and S63 (E40xE33) was incorporated in the 1973 crossing program.

Variation in the success rate of controlled crossing between years was considerable ranging from 84 per cent for Leiria in 1965 to a low 43 per cent in 1968 (Table 10). The low result in 1967 also occurred with Landes crosses which were normally most successful.

TABLE 10

Size and success of controlled pollinations carried out with Leirian pollen from 1965 to 1972.

FEMALE RAMET	YEAR OF POLLINATION							
	1965	1966	1967	1968	1969	1970	1971	1972
Leiria								
No. attempted	884	720	719	696	926	693	882	594
Survival (%)	84	62	49	43	80	67	55	77
Landes								
No. attempted	45	22	97	23		22		
Survival (%)	100	68	40	87		95		
Corsican								
No. attempted	11	17	14			21		
Survival (%)	27	6	14			0		

TABLE 11

Influence of clone origin and ramet location on the success of pollination.

YEAR	SOURCE OF CLONE	LOCATION OF RAMET	CROSSINGS ATTEMPTED	SUCCESS (%)
1968	Imported	Arboretum	333	33
	Imported	Orchard	184	51
	Local	Arboretum	185	43
1969	Imported	Arboretum	623	80
	Imported	Orchard	64	84
	Local	Arboretum	239	77

Apart from near-failure of attempted matings of Leiria pollen onto Corsican conelets no general pattern to the variation in successful pollinations between phenotypes could be detected. Seasonal variation (Table 11), associated with climate and weather conditions, appeared to have been the dominant influence. This was later evident in the cone yields from the seed orchards.

Inter-provenance Crosses- A special effort was made in 1968 and 1969 to cross other provenances of *P. pinaster* with the Leirian provenance. Attempts to cross Leirian pollen with Corsican clones in 1965, 1966, 1967 and 1970 were disappointing (Table 10). Stored pollens of Corsican and Landes trees were tested on Portuguese clones for the first time in 1969. This was highly successful and proved the only effective procedure to obtain Corsican x Leiria crosses.

Cone Development - Successful pollinations were assessed in the following spring after cone growth started, 14 months after pollination. These conelets were covered with a calico bag to prevent bird damage (Fig. 13). Unbagged cones resulting from open pollination were removed from the trees to avoid attracting birds to the arboretum. Generally, even with selfings, pollination was successful but seed yield varied considerably with cone size both in seed number and weight. Cones were opened by drying in the sun on the glasshouse bench and seed was stored in airtight containers under refrigeration. Good matings provided up to 95 per cent of viable seed.

A total of 830 families were produced from the pollination program and registered in the pedigree seed database.

Figure 14. Clones in the Neaves Road Arboretum during the pollination season.

Seed Production

Introduction

From 1939-1945, in the absence of an overseas supply during World War II, some seed was collected from local plantations for planting. Costs were high from the young sparse plantations. Further, the extensive depredations of the black cockatoo on cone crops of the limited plantation areas was devastating (Fig. 15).

In the postwar period, 1950-1970, seed for plantation extension of up to 1000 ha per year was imported from Portugal. Arrangements made with the British Forestry Commission and the Portuguese Forest Service guaranteed the supply to be from the Forest of Leiria. It was cheaper to import cleaned seed than to collect and process local seed.

Production Stands - In 1969, to advance the supply of improved seed, a seed production area was planned in the 1941 plantings of Portuguese stock at Gnangara plantation. This stand, originally planted at 2 m x 2 m spacing on a good site, had been used for thinning studies in 1957. Heavy thinning from 2900 to 360 or 240 stems ha^{-1} left an excellent crop of well formed final crop trees (Fig. 16).

Approximately 16 ha of the stand was heavily fertilized with nitrogen and phosphorus fertilizers. Significant quantities of seed became available and in 1972, 109 kg of clean seed was obtained from this source.

No further collections were made from this production stand as yields from the initial seed orchard became available to meet all requirements.

Seed Orchard Requirements

The Orchard Concept - The concept of a seed orchard (Faulkner 1975) is to plant desirable genotypes in a random manner to favour outcrossing (polycross). This area should be managed to produce an economical cone crop for operational purposes.

Clonal material is usually preferred to seedlings for orchard establishment as mature characteristics of the ortet transmitted by asexual means provide for early and heavy flowering in the ramets. This particularly applies to pollen production. Vegetative propagation also introduces the full genetic potential of the parent to the production area.

Ideally, an orchard should have negligible contamination from external pollen sources and an adequate number of clones to reduce inbreeding which can cause low seed yields and restricted vigour in offspring.

Good soils, spacing, fertilizer application, artificial pollination, insect sprays and irrigation can be used to maximize the seed yield.

Design of the orchard should favour ease of cone collection from mobile platforms or tree lopping to maintain shoot and cone production at low stem heights.

Early Cone Collection - Successful orchard planning for *P. pinaster* in WA required a strategy to reduce the damage caused by the black cockatoo to cone crops.

Cones on the trees normally ripen to a full brown colour in spring, two years after pollination. The best time for collection for ripe seed was considered to be in October and November. Bird feeding on the ripening

Figure 15. Normal and damaged cones resulting from cockatoo activity.

Figure 16. A heavily thinned stand of 18-year-old plantation prepared for a seed production area.

cones was greatest from May to December continuing throughout the summer on the ripe crop.

In the early 1940s, a series of trials were carried out to see whether cones could be picked early to reduce damage by the cockatoo. Ripening cones at the Somerville plantation were collected in 1941 and 1942, at monthly intervals from February to December. The seed was extracted immediately after collection and stored for testing in the following spring and summer. In 1943, 1944, 1945 and 1946 cones were collected monthly and stored on the ground under a layer of pine needles to ripen. All seed was extracted from them in summer, cleaned and tested.

Results (Table 12) were variable but indicated that cones collected as early as March could produce viable seed if it were allowed to ripen in the cones before extraction in summer.

A further study in 1967 determined the earliest month that maturing cones could be satisfactorily removed from the tree for operational seed extraction (Hopkins 1971). This trial was conducted in the Neaves Road Scion Arboretum and included several clones to assess variability. Cones were collected monthly and stored in the cool of the laboratory. Seed was extracted, stratified and germinated in November and December.

Seed weights were lowest in the January and February collections. Seed from most clones reached maximum weight by April. Generally, most seed collected after March appeared to be normal in colour and size. Germination percentages varied considerably between clones but both the March and May collections (Table 13) produced high germination.

Research with other pine species (Winston and Haddon 1981; Cobb *et al.* 1984) has also shown that cones can be artificially ripened provided that embryo growth has been completed prior to picking.

In orchard management it has been necessary to install gas scare guns to operate during daylight from early December to mid May each year. Work such as pruning, thinning and fertilizer application is also scheduled to provide a physical presence in the orchard over these critical months to further deter the cockatoos. Cones have been collected in late April to mid May and stored in a cool place to ripen. The seed has been extracted in summer.

Orchard Development - A prime objective of the breeding program was to obtain improved seed for commercial plantation use from clonal seed orchards as soon as was practicable.

The first plus trees were selected in 1956 and the initial seed orchard at Joondalup was commenced in 1962 and completed in 1963. The second, comprehensive, first-generation orchard was begun in 1969 and completed in 1972 at Mullaloo. All seed requirements for commercial use have been met from the orchards since 1971, providing for some 13 000 ha of plantation.

The clonal orchards at Joondalup and Mullaloo were established with untested clones. Once data from progeny testing became available these clones were culled to remove the poorest parents.

TABLE 12

Percentage germination obtained from cones picked in different months. In 1941 and 1942 the seed was extracted on collection but from 1943 to 1946 cones were allowed to ripen prior to extracting the seed in summer.

COLLECTION	YEAR OF COLLECTION					
month	1941	1942	1943	1944	1945	1946
February	-	0	-	-	-	-
March	-	8	-	87	-	65
April	20	26	40	92	83	71
May	7	24	24	81	80	61
June	16	29	29	69	89	90
July	25	34	35	90	88	27
August	31	27	26	77	70	79
September	28	41	26	77	88	78
October	33	30	21	91	83	52
November	41	36	-	-	85	-
December	-	29	-	-	-	-

TABLE 13

Percentage germination from immature cones collected at monthly intervals from Neaves Scion Arboretum and allowed to ripen prior to seed extraction in November.

CLONE	MONTH OF COLLECTION									
	J	F	M	A	M	J	J	A	S	0
E19	0	13	47	59	4	73	1	15	42	42
E22	4	4	87	44	94	99	99	69	96	91
E37	0	0	57	21	53	63	63	65	71	29
Mean	1.3	5.7	64	41	65	78	54	50	69	54

A second generation clonal orchard, completed at Manjimup in 1990, incorporated only proven parents and recombinations of the plus trees. Selection standards were higher and included wood quality. It is anticipated that this orchard will meet all State requirements for seed after 1995.

Progeny trials from random pair matings have been planted at Busselton with a secondary objective to serve as control pollinated seedling seed orchards. Approximately 19 ha are involved and they are surrounded by *P. radiata* to reduce external pollen contamination. Although these could be considered for commercial seed yields it is improbable that they will be required because of the adequacy of clonal orchard supplies.

Seed handling and nursery skills were developed alongside the seed orchard program.

Joondalup Orchard

The Joondalup orchard of 10.5 ha was sited on good planting country some 3.5 km north of the Wanneroo breeding station. The site is some 8.3 km west of the plantations and is easily accessible to the breeding station. The winds in September, when pollen is releasing, are predominantly from a westerly direction and unfavourable to pollen drift to the orchard site. Fire protection, seen as essential, was manageable on the site.

Pollen Drift - A study to assess the amount of fine pollen drifting over the location from external sources was carried out prior to selecting the orchard site. Traps were set around the location and four were established on the proposed orchard area.

The traps consisted of two aluminium discs 23 cm in diameter, assembled parallel to each other at a distance of 13 cm. A small bench consisting of an aluminium strip 13 cm long by 4 cm wide was set between them, centrally, at about 5 cm above the lower disc. On this an aluminium slide containing five 9.5-mm diameter holes was mounted. A strip of waterproof, pressure-sensitive tape was fixed to the underside of the slide (Grano 1958; Hoekstra 1965). Any pollen falling into the holes was caught and held on the tape. The assembled traps were mounted horizontally on a 1-m long metal rod pushed into the ground to a depth of 30 to 50 cm.

The traps were placed in position on 21 August 1962 and the first pollen grains were collected on 5 September. Counts were made at weekly intervals, a clean slide being inserted at each change. Figure 17 shows the maximum and minimum number of pollen grains measured in any of the four traps each week.

The heaviest drift occurred during the week 12-19 September and ranged from a minimum of 17 pollen grains per square centimetre to a maximum of 32 grains per square centimetre for the 7-day period. This was heavier than expected considering there is a separation distance of some 8 km from the nearest plantation (Boyer 1966). It is, however, within limits usually accepted as tolerable (Wright 1953; Wang *et al.* 1960) and would have an insignificant impact on the orchard when the clones in situ were producing a pollen cloud.

Design - Convention at the time (1961) suggested that 12 to 16 clones were required in an orchard to satisfactorily reduce inbreeding effects. The best 16 of the local plus trees were selected for the orchard.

The orchard was designed for planting of ramets at 7 m x 7 m spacing within a polycross layout. Randomization was within a block of 256 ramets which was replicated over the orchard area (Appendix V). Adjustments were made to ensure that no two ramets of the same clone were adjacent.

Establishment - The first planting was in 1963 when more than half of the area was established with 1487 ramets. A further 975 ramets were planted in 1964 to complete the orchard.

In 1966, 546 ramets, embracing 41 of the imported clones, were interplanted in the orchard in an endeavour to increase the genetic base. It was realized that even with future thinning these later plantings would have a limited contribution to the cone crop, but a significant improvement of the pollen source was expected.

Maintenance - Fertilizer was added to the planting hole at planting and in 1968 and 1969 crossed fertilizer strips were applied to determine the effects of added nutrients on seed yield. Fertilizer trials were also conducted in 1972. Results were difficult to interpret but high levels of nutrients were beneficial. A dressing of zinc-copper-superphosphate and a mixed nitrogen-phosphorus-potassium (Vigran) fertilizer was later applied every two years to promote production.

Up to 1970, the orchard was disc-harrowed or rotary hoed around the trees in October to control weeds. After 1970 the weeds were rotary slashed to ground level.

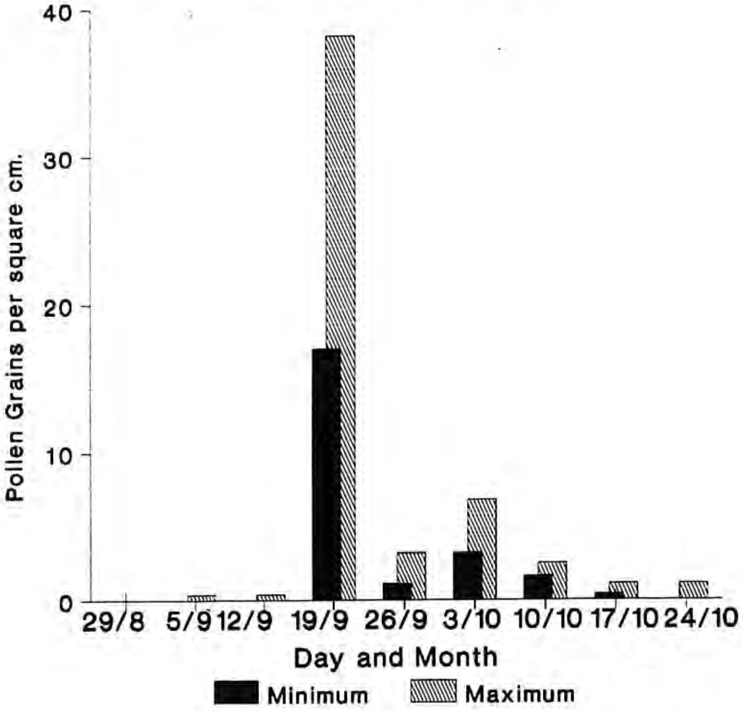

Figure 17. Maximum and minimum counts of extenal pollen drift at the Joondalup orchard site.

TABLE 14
Yield data for the Joondalup seed orchard.

COLLECTION		PRODUCTION		YIELD STATISTICS			
YEAR	AGE (YEARS)	NO. OF CONES	SEED WEIGHT (kg)	CONES PER TREE	SEEDS PER CONE	WEIGHT OF 100 SEEDS(g)	WEIGHT SEED/HA (kg)
1968	5-6	3 385	13	1.5	85	4.5	1.2
1969	6-7	11 490	51	5.1	81	5.4	4.7
1970	7-8	14 147	70	5.5	80	6.2	6.7
1971	8-9	46 637	259	19.0	116	4.3	24.5
1972[a]	9-10	29 392	142	10.0	121	4.7	13.5
1973[a]	10-11	25 268	109	4.5	121	5.3	6.1
1974[b]	11-12	32 000	160	10.0	141	5.5	15.2
1975[b]	12-13	22 800	116	10.5	-	-	11.1
1976	13-14	29 700	155	25.0	-	-	14.8

[a] Pruning to height 1.5 to 2.0 m.
[b] Culled from 2 480 to 1 690 trees.

In 1972 and 1973 stems were pruned to a height of 2 m to assist access and to promote fire protection. This work was delayed in some areas to favour pollen production and to save existing cones on the larger lower branches. The orchard was thinned in 1974 and 1975 from 2480 of the local grafts to 1690 trees. In this 30 per cent thinning, six of the original 16 local clones were culled from the orchard on the basis of their poor performance in progeny tests. The contribution of the interplanted Portuguese clones permitted this necessary, but heavy, reduction in the original number of clones.

Cones were collected in May by climbing, where necessary, to dislodge them with a special crook. As trees developed in height, platforms on a vehicle were used.

Seed Yields - In the absence of local pollen, flowers in the orchard trees were hand pollinated in 1965 and 1966. A different pollen was used in each block of the orchard. The seed obtained was used in a yield trial planted in 1970. In September 1967 nine of the 16 clones were observed to have heavy pollen production. The first commercial yields were collected from the orchard in 1968 and 1969 (Table 14).

Peak seed yield was achieved in 1971, some seven to eight years after establishment of the ramets. This exceptional yield is partly ascribed to a dry winter and spring in 1969, the year of the pollen set, followed by a wet January in 1970. It was also associated with heavy nitrogen-phosphorus fertilizer application to the orchard in the preceding years. A maximum of 24.5 kg of seed per hectare was obtained and maturity in seed weight and cone size had been attained by that time.

Yields subsequent to 1971 were variously influenced by pruning removing the lower branches and by the culling carried in 1974 and 1975. Results (Table 14) indicated that the continuing capacity of the orchard for production should average at least 15 kg ha^{-1}. Crops were not harvested after 1976.

The Joondalup Orchard was superseded by Mullaloo Orchard in 1976 and the area is now being developed for recreational purposes.

The Mullaloo Orchard

The second seed orchard, at Mullaloo, was begun in 1969 and completed in 1972. It occupies 10.1 ha of a flat to gently undulating site with good quality sandy soils. The site is several kilometres further west of the Joondalup orchard and has excellent separation from external pollen contamination. It is readily accessible from Wanneroo. Originally it contained 7816 ramets planted in blocks which contained from 54 to 95 clones (Table 15). It has now been culled to 1480 ramets.

Design - Mullaloo was designed to make use of the wide range of plus trees available following the importation of clones from Portugal in 1964-65.

Spacing aimed for high early seed yields, through relatively high stocking, with the objective of progressive culling to the best 25 clones as progeny test data became available. Grafts were planted in adjacent rows at 3 m x 3 m spacing with a bay of 6 m between each pair of planted rows (Appendix V1). The bay provided for access and cultivation as well as ensuring growing space, on at least one side of each tree, until the orchard was culled. Most trees were virtually free grown in the early development stages and gave a better pollen production for an early cone and seed production.

TABLE 15
Structural details for the Mullaloo seed orchard.

YEAR PLANTED	NO. OF RAMETS	NO. OF CLONES	AREA (ha)	CLONES REMAINING AFTER CULLING IN			CURRENT STOCKING (stems ha^{-1})
				1978	1981	1985	
1969	929	54	1.3	47	47	32	149
1970	2 668	95	2.9	61	61	41	158
1971	3 264	94	4.5	94	45	45	133
1972	955	92	1.4	92	45	45	160
Total	7 816	96	10.1				146

Of the 96 clones used in the orchard, 55 were imported from Portugal, 38 were from local selections and three were from South Australia.

The vigour of the imports under local climate and soil conditions was in doubt at the time of planting. To compensate for any deficiency in this respect two ramets of one of the best 12 local clones were planted for each Portuguese ramet.

Flexibility for the clonal compliment was seen as essential in this orchard design. Observations in the Joondalup Orchard and Neaves Road Arboretum had shown wide variation in critical flowering times and abundance of flowers between clones (Tables 16 and 17). These variations could be compensated for by thinning and culling, within the developing orchard.

Establishment - Planting and early maintenance was a costly procedure. Holes, approximately 60 cm deep, were drilled in the selected plant locations with a tractor-mounted auger. Two people were required for planting to remove the stock from the can or plastic container, spread the roots, position the plant in the hole and fill in. A handful of Magamp slow release fertilizer was placed at the bottom of each hole and trees were planted about 3 cm below the nursery depth. A handful of super-copper-zinc fertilizer was also spread on the surface adjacent to the stem.

The large root stocks employed for grafting required the ramets to be supported by a hardwood stake for the first two years in the orchard. In the last year of planting at the orchard, holes were drilled to about 80 cm depth and ramets were planted much deeper to about 10-20 cm below the graft union. This increased the stability of the graft and removed the need for staking and for rootstock pruning. This practice has been used for all subsequent planting out of grafts.

Of 7816 grafts established, refills were required for only 3.5 per cent.

Maintenance - Weeds were suppressed by slashing and nitrogen-phosphorus-potassium fertilizers were added every three to four years. The lower branches of each ramet to 2 m height were pruned, as was convenient. Pruning and thinning debris was removed from the site and burnt. An attempt in 1979 to establish clover varieties in the bays between the trees was only partly successful. Up to 1987, gas-operated scare guns were employed to deter cockatoos from destroying the cone crop.

Culling - The original concept of the Mullaloo Orchard was to select within the original number of up to 96 clones in order to leave the most suitable 25 for seed production.

In September 1978 the areas planted in 1969 and 1970 were culled to remove 11 local and six imported clones which showed unsatisfactory performance in progeny trials. The remaining clones were partly thinned. This left 47 clones at an average stocking of 370 stems ha^{-1} on the areas. In May 1981 the orchard area planted in 1971 and 1972 was also culled from 740 to 370 stems ha^{-1} to leave an average of 45 clones.

Further culling in 1985 followed a strategy to leave:

3 times the basic ramet number for outstanding clones;

2 times the basic ramet number for very good clones;

1 times the basic ramet number for good clones.

This left an average stocking of 145 stems ha^{-1} (Table 15).

Thinning and culling reduced the original 7816 ramets to the most favourable 1480, an 80 per cent reduction.

Seed Yield - The maximum yield of 283 kg of seed was obtained in 1981 (Table 18). The failure of the gas scare gun in 1979 saw the entire crop of the Mullaloo orchard, estimated at some 150 bags of cones, lost to the birds over one weekend.

Culling, thinning and partial losses of crops to birds make it unrealistic to estimate an optimum or maximum yield from the area.

TABLE 16

Variation in the average weight of 100 seeds provided by the clones in the developing Joondalup seed orchard.

CLONE	NO. OF RAMETS	MEAN WEIGHT OF 100 SEEDS (g)				
		1967	1968	1969	1970	1971
E2	157	5.9	4.9	6.2	-	-
E5	158	5.1	5.2	6.5	5.9	4.6
E14	150	4.6	4.3	4.6	-	-
E15	158	3.3	4.2	5.3	-	-
E19	151	5.9	6.1	6.8	6.9	4.2
E28	157	4.7	4.8	5.0	-	-
E31	159	4.5	4.7	5.7	-	4.6
E33	154	3.6	4.2	5.3	5.6	4.0
E40	152	3.5	3.5	4.5	3.7	3.2
E41	157	5.7	5.7	6.1	5.4	5.0
E45	159	4.3	4.5	5.1	-	-
E46	153	3.7	4.1	4.6	-	-
E47	155	3.3	4.0	4.4	3.4	-
E49	153	3.8	3.6	4.8	-	-
E50	151	3.7	3.9	5.0	-	-
E53	157	4.6	4.7	5.2	-	-
Mean		4.3	4.5	5.3	5.2	4.3

TABLE 17

Variation in the mean number of cones produced per clone in the Joondalup seed orchard.

CLONE	NO. OF RAMETS	YEAR OF COLLECTION					
		1967	1968	1969	1972	1973	1974
E2	157	0.0	0.0	0.2	1.5	0.3	1.8
E5	158	0.1	0.8	6.3	8.7	7.0	10.7
E14	150	0.2	0.9	1.7	10.0	8.0	6.0
E15	158	0.1	0.8	0.3	3.5	10.3	8.3
E19	151	1.8	2.2	15.1	27.8	16.3	27.9
E28	157	0.5	0.9	1.6	5.0	5.3	3.3
E31	159	0.2	0.1	0.4	4.3	1.0	0.8
E33	154	0.3	0.8	3.3	9.4	6.0	14.4
E40	152	1.7	2.5	10.2	15.7	12.4	12.1
E41	157	0.4	1.3	3.2	8.6	11.3	6.5
E45	159	0.5	0.8	1.2	6.5	8.3	3.2
E46	153	1.4	1.0	4.4	3.7	8.5	8.1
E47	155	0.2	0.4	2.7	10.0	16.1	15.7
E49	153	1.3	4.6	18.3	28.8	22.3	15.9
E50	151	0.6	1.9	3.5	12.0	13.3	6.8
E53	157	1.2	2.7	11.2	35.0	17.6	20.4
Mean		0.7	1.3	5.1	11.9	9.7	10.0

TABLE 18

Yield data for the Mullaloo orchard.

COLLECTION YEAR	ORCHARD AGE	WEIGHT 100 SEEDS (g)	SEED YIELD (kg)
1975	3-6	-	24
1976	4-7	-	77
1977	5-8	4.5	103
1978[a]	6-9	4.2	148
1979	7-10	5.6	9
1981[b]	9-12	5.0	283
1982	10-13	5.4	137
1983	11-14	5.7	108
1984	12-15	4.6	172
1985[c]	13-16	4.8	128
1987	15-18	5.9	19
1988	16-19	6.6	17
1989	17-20	4.8	257
1990	18-21	4.8	107
1992	21-24	5.7	55

[a] Culling and thinning of 1969-1970 stand.

[b] Culling and thinning of 1971-1972 stand.

[c] Culling and thinning to 145 stems ha^{-1}

With recent urban development it is now no longer acceptable to use the noisy scare gun at Mullaloo and bird damage to the crop can be expected to be severe each year. However, even with the expected damage to annual crops in the absence of this deterrent, a sufficient supply of cones for local requirements should be available. Demand for the land for residential development jeopardizes the long-term future for Mullaloo Orchard. It is hoped to retain most of the clones by converting the area into a recreation complex as part of the Joondalup campus of the Edith Cowan University.

Progeny Testing

Introduction

The plus tree selected in the plantation is the physical expression (phenotype) of the genetic potential (genotype) of the individual and its interaction with the environment in which it developed. A plus tree may be tall and/or straight because of a favourable genotype for height or straightness, because of favourable growing conditions or because of interactions between these factors.

The genotypic content of an individual, or family, can only be evaluated or expressed by specially designed tests which account for the variation owing to the environment in the phenotypes measured. Tests of offspring or progeny show the degree that the trait or character under consideration (height, diameter, stem straightness, branch size) are transmitted to offspring (inherited values) and to what extent they are related (heritable).

Many characters are transmitted independently of each other and testing can be quite complex. It is not practicable to test for the full expression of all characters at any one time and under any one set of conditions. Successful progeny testing requires skill and planning to employ tests to meet program requirements.

Progeny testing can be expensive in time and money depending on the age to which the progeny must be maintained for evaluation, the number of characters to be defined and the accuracy of definition required. For breeding it is preferred to conduct the minimum number of tests which define the parents producing the desirable level of character expression (stem volume, straightness, branch size) in their offspring. This desirable character expression, breeding objective or standard of crop to be achieved, must be realistic and determined within practical silvicultural, processing and marketing standards.

The success of progeny testing is hence not solely dependent on the techniques or test procedures employed. It depends largely on the practicability of the objectives set for the breeding program and the value that can be ascribed to the improvement of the final product.

Heritability - Phenotypic performance (P) can be considered as a linear combination of genotypic value (G) and environmental deviation (E):

$$P = G + E$$

If G and E are not correlated, the variance of the phenotypic values is also a linear combination of their variances:

$$V_p = V_G + V_E$$

The ratio

$$h^2 = V_G/V_P = V_G/(V_G + V_E)$$

is the 'heritability' of the character in that particular population.

General and Specific Combining Ability - Progeny testing aims to evaluate the genetic potential of parents under environmental conditions relevant to plantation practice. A parent can transmit the desirable characteristics through general crossing with other parents (general combining ability or GCA). This is the situation in the polycross seed orchard where offspring result from crossings between a range of desirable parents.

Heritability also concerns the specific combining ability (SCA) or the expression of characters from the combination of any two particular parents. This can be particularly important in clonal propagation and for long-term breeding requirements. Whereas GCA refers to additive effects transmitted in sexual outcrossing, SCA includes non-additive effects that are only effectively transmitted to offspring by asexual procedures such as cuttings or grafting.

On the basis of the values obtained for general and specific combining ability and favourable genetic correlations, parents will be retained or discarded from the breeding program.

The Testing Program

Progeny testing commenced in 1961 when knowledge was limited on practicable designs for the purpose, the impacts of cultural treatments and the variability within local sites (Lee 1983; Lambeth *et al.* 1983; Cotterill and James 1984; Loo-Dinkins and Tauer 1987). To some extent, therefore, progeny test development has been one of improvisation and gradual improvement.

Objectives - Objectives for progeny testing were set in 1964 as follows:

1. to aim for the earliest evaluation of clones in the seed orchard to allow culling and improvement;
2. to represent trials on the sites and under the silviculture conditions to be used for future *P. pinaster* establishment in WA;
3. to provide the necessary heritability values to conduct a second generation program;
4. to view trials as selection areas where new families or recombinations of plus trees would be produced for second generation orchards.

General guidelines adopted to meet these objectives covered the following main points:

1. Progenies, or trials, would be planted on at least two sites to cover the range of climates and soils associated with planting sites in WA. Trial replication was also considered essential to reduce possible impacts of wildfires on the testing program.
2. Simple, complete randomized block experimental designs would be used, concentrating on uniformity within blocks.
3. Each trial would include up to four common families to link comparisons between sites and between years of planting.
4. At least 100 seedlings of each progeny could be incorporated in a trial. Initially it was considered that a five- to ten-tree unit plot was required to provide useful means for analysis. In later trials with large numbers of families, intended particularly for second generation selection, single-tree plots were used to reduce the size of the experimental blocks
5. Tubed stock and uniform, intensive silviculture would be used to restrict variation resulting from mortalities, refilling and uneven growth of trees in plots.
6. A control consisting of seedlings raised from the routine batch of seed imported from Portugal for operational use, would be incorporated in trials to provide an early indication of improvement achieved.

The possibility of using the progeny test for seed production was considered. However, the likelihood of inbreeding owing to the testing system adopted and field damage by cockatoos negated the value of most progeny tests as useful seed production areas.

Nomenclature - Full-sib trials were designated YS and numbered consecutively from 1 to 68 to distinguish them from predominantly half-sib trials designated XS (Table 19). The few trials not controlled with an accepted statistical field plot design were designated YR or XR. The different types of trial have different maintenance and measurement requirements and value to the program.

The Program - The first progeny trials in WA were planted in 1965 with seed produced from the 1961 controlled pollinations. The low numbers of seeds and their relative expense led to the raising of seedlings in 10-cm deep clay pots to minimize nursery and establishment losses. The trials were designed to accommodate the range of plants available.

The first full-sib tests (YS01, YS02) were planted out as Latin squares with 7 families using a 9- and 6-tree rectangular plot, respectively, as the basis of comparison for each family. Standard statistical designs may cater for the variation within families, between families and between sites to determine the environmental influences in future measurements of the progeny phenotypes (Cochran and Cox 1957).

Six trials (XS01 to XS06) were established in 1966 using bare-rooted seedlings from half-sib seed imported from the Portuguese selections of plus trees. These were in 5 x 5 Latin square designs with at least one family common to each trial to provide linking for comparisons. Greater variation was expected from the bare-rooted, half-sib seedlings through nursery differences, establishment mortality and the multiple paternal genotypes involved. This was compensated for by using closely spaced 48-tree plots as the initial unit for comparison.

Trial establishment continued until 1978 by which time a total of 86 trials (Table 19), embracing a management area of 195 ha, had been planted. For all trials intensive site preparation, early fertilizer application and weed control were carried out. The initial spacing of 3 m x 3 m was used to provide good early growth and allow thinning to be delayed until after a complete assessment of growth was carried out at age nine years. The objective was to provide a breeding population adapted to the intensive silviculture required in modern plantations.

Height was measured at age 3.5 years and diameter at 8.5 years. Trees were pruned to a height of 2 m prior to the diameter measurement. This facilitated the assessment of tree form at the time of the diameter measurement. Trials were considered to be completed after the measurements at nine or ten years.

Many progeny trials have been measured more frequently and for different parameters and several have received intensive management and measurement over the rotation to provide genetic information on juvenile-mature correlations. Several have also been used for fertilizer (YS35, YS36), thinning (YS06, YS11, YS13) and high pruning (YS07, YS12) studies. One trial at Mundaring (YS05) was converted into an agroforestry study.

Most trials were thinned and high pruned, after the initial set of measurements, and managed as demonstration areas of intensive forestry and the integration of tree breeding with optimum silviculture.

Implementation

Progeny testing was completely dependent on the success of the controlled pollination program and the availability of adequate seed lots. At least five years lapsed between planning, pollinating, collecting seed, raising seedlings in the nursery and planting the trial in the field. A normal sequence was the following:

YEAR 1.	Plan program. Store pollen (September).
YEAR 2.	Pollinate. (September).
YEAR 3.	Cone development.
YEAR 4.	Extract seed (November).
YEAR 5.	Prepare and sow tubes (August).
YEAR 6.	Prepare site. Plant trial (June). Fertilize.
YEAR 8.	Control weeds with cultivator.
YEAR 10.	Measure height (January).
YEAR 12.	Fertilize.
YEAR 13.	Prune to 2 m.
YEAR 15.	Measure diameter and form (February).
YEAR 16.	Thin. Prune to 5 m.
YEAR 16.	Select second generation parents.

Variation in pollination results and, to a lesser extent, nursery performance, greatly influenced the number and quality of plants available for testing. Often the final details of families, plant numbers, replication, trial design and location were not available until about April in the year of planting (Year 6).

Use of Testers - Progeny plantings for the pollen tester phase of the program were completed in 1974. Some 68 trials were involved, if all 53 full-sib and 15 half-sib tests considered important at the outset are included. Basically these are complete, randomized block experiments with 20 to 30 families of 5- to 10-tree line plots, generally replicated in 10 blocks (Table 19).

The program also includes trials with seed of South African origin (YS55, YS63) and Trial YS56, using 65 South African families from a 5-tester system for evaluation. Seed from the tester phase was also sent to Canberra, Victoria, South Australia, New Zealand and South Africa (Appendix XI) to further obtain information on genotype x environment interactions.

Random Pair Mating - Random pair mating produced a total of 228 new families for future selection. The associated field plantings covered 11 trials and these were completed in 1978. A larger number of families were involved in these trials (Table 19).

Tubing - The practice of raising tubed seedlings was developed to a high degree of competence during testing. Seed available was used efficiently, seedlings were healthy and uniform in size and seedling survival in the field was almost 100 per cent.

The 10 cm clay pots used initially in 1964 were replaced by ply veneer tubes 20 cm deep and 4 cm diameter. The veneer was held in place by a polythene sleeve which also prevented evaporation from the sides of the tube (Fig. 18). Tubes were filled with a standard potting mix of 3 parts sand, 1 part loam and 1 part peat moss, containing a mixed fertilizer. These were positioned in frames (Fig. 19) in the nursery. It was later found to be more convenient and economical to replace the veneer-polythene tubes with specially prepared, strong polythene bags. These were 20 cm deep and 5 cm in diameter and were easier to store and fill.

Seed was stratified (Hopkins 1971), the non-viable portion being removed as floaters in the process of cold soaking in water prior to stratification. After dusting with a fungicide, it was directly sown into the tubes, in August. A small surplus was sown to provide for refilling. Germination averaged in the order of 89 per cent and any failures were refilled with seedlings pricked out from the surplus. Watering was initially by hand-held hose, to ensure even distribution and to avoid waterlogging, and later, by overhead irrigation.

Normally, from 50 to 150 healthy seedlings were required for each family in a single trial but for the standard, linking families and the routine control, up to 600 could be required. Approximately 19 000 tubes a year were handled at the peak of progeny testing (Table 20).

TABLE 19

Summary of Western Australian *Pinus pinaster* progeny tests.

TRIAL NO.	YEAR	LOCATION	NUMBER OF			TREE PLOT	PLOT TYPE	MATING DESIGN[a]
			PARENTS	FAMILIES	BLOCKS			
YS01	1965	Gnangara	7	7	7	9	Square	2
YS02	1965	Gnangara	6	7	7	6	Rect.	2
YS03	1966	Gnangara	12	13	20	10	Line	2
YS04	1966	Gnangara	13	16	10	6	Rect	2
YS05	1966	Mundaring	11	13	20	5	Line	2
YS06	1966	Yanchep	8	8	8	8	Rect	2
YS07	1966	Yanchep	12	12	10	3	Line	2
YS08	1967	Gnangara	12	20	10	10	Line	2
YS09	1967	Yanchep	9	20	10	10	Line	2
YS10	1967	Mundaring	8	20	20	5	Line	2
YS11A	1968	Gnangara	11	30	8	10	Line	2,3
YS11B	1968	Gnangara	11	30	8	5	Line	2,3
YS12	1968	Gnangara	13	21	10	10	Line	2
YS13A	1968	Yanchep	11	30	8	10	Line	2,3
YS13B	1968	Yanchep	11	30	8	5	Line	2,3
YS14	1968	Manjimup	9	20	8	10	Line	2
YS15	1968	Collie	9	10	5	20	Line	2
YS16	1968	Mundaring	11	16	10	5	Line	2
YS17	1968	Hamel	12	24	7	3	Line	2
YS18	1969	Gnangara	17	32	12	5	Line	2,3
YS19	1969	Yanchep	17	32	12	5	Line	2,3
YS20	1969	Gnangara	19	32	8	5	Line	2,3
YS21	1969	Yanchep	19	32	8	5	Line	2,3
YS22	1969	Gnangara	19	27	10	16	Square	2,3
YS23	1969	Manjimup	12	32	12	5	Line	2,3
YS24	1969	Manjumup	18	32	8	5	Line	2,3
YS25	1969	Hamel	14	30	10	3	Line	2,3
YS26	1969	Hamel	17	26	10	3	Line	2,3
YS28	1970	Gnangara	16	34	8	10	Line	2,3
YS29	1970	Yanchep	16	34	8	10	Line	2,3
YS30	1970	Gnangara	21	34	6	10	Line	2,3
YS31	1970	Yanchep	21	34	6	10	Line	2,3
YS32A	1970	Gnangara	20	30	9	5	Line	2
YS32B	1970	Yanchep	20	30	3	5	Line	2
YS33	1970	Gnangara	12	16	6	16	Square	5,2
YS34	1970	Hamel	21	34	10	3	Line	2
YS35	1971	Gnangara	8	15	4 x 6	6	Single	3
YS36	1971	Gnangara	8	15	3 x 6	6	Single	3
YS37	1971	Gnangara	18	25	20	5	Line	2
YS38	1971	Yanchep	15	17	20	5	Line	2
YS39A	1972	Gnangara	10	15	5	5	Line	3
YS39B	1972	Pinjar	10	15	5	5	Line	3
YS40	1972	Gnangara	28	34	10	5	Line	2,3
YS41	1972	Pinjar	23	34	10	5	Line	2,3
YS42	1972	Gnangara	28	30	10	5	Line	2

TABLE 19 (continued)

Summary of Western Australian *Pinus pinaster* progeny tests.

TRIAL NO.	YEAR	LOCATION	NUMBER OF			TREE PLOT	PLOT TYPE	MATING DESIGN[a]
			PARENTS	FAMILIES	BLOCKS			
YS43	1972	Pinjar	28	30	10	5	Line	2
YS44	1972	Gnangara	30	30	10	5	Line	2
YS45	1973	Gnangara	40	48	10	5	Line	2,3
YS46	1973	Yanchep	41	48	10	5	Line	2,3
YS47	1973	Gnangara	42	48	10	5	Line	2,3
YS48	1973	Gnangara	24	24	10	5	Line	2,3
YS49	1974	Gnangara	18	80	10	5	Line	2,3
YS50	1974	Jarrahwood	18	80	10	5	Line	2,3
YS51	1974	Gnangara	14	30	10	5	Line	5
YS52	1974	Yanchep	13	28	10	5	Line	5
YS53	1974	Jarrahwood	13	28	10	5	Line	5
YS54	1975	Gnangara	91	81	50	1	Single	4
YS55	1975	Gnangara	87	81	21	1	Single	4
YS56	1975	Gnangara	20	63	6	5	Line	3
YS57	1976	Gnangara	107	60	12	4	Square	4
YS58	1976	Gnangara	94	54	12	4	Square	4
YS59	1976	Gnangara	80	45	12	4	Square	4
YS60	1976	Gnangara	79	45	12	4	Square	4
YS61	1976	Jarrahwood	64	35	8	4	Line	4
YS62	1977	Gnangara	22	30	5	5	Line	4
YS63	1977	Jarrahwood	18	20	5	5	Line	4
YS64	1978	Gnangara	22	26	10	5	Line	4
YS65	1978	Gnangara	99	54	8	4	Line	4
YS66	1978	Jarrahwood	65	36	8	4	Line	4
YS67	1983	Collie	35	30	6	8	Line	6
YS68	1991	Jarrahwood	16	8	20	1	Single	4,7
XS01	1965	Gnangara	5	5	5	48	Rect.	1
XS02	1965	Gnangara	5	5	5	48	Rect.	1
XS03	1965	Gnangara	5	5	5	48	Rect.	1
XS04	1965	Gnangara	5	5	5	48	Rect.	1
XS05	1965	Gnangara	5	5	5	48	Rect.	1
XS06	1965	Gnangara	5	5	4	48	Rect.	1
XS07	1966	Gnangara	40	40	12	10	Line	1
XS08	1966	Mundaring	20	20	10	10	Line	1
XS09	1966	Gnangara	41	40	8	10	Line	1
XS13	1973	Gnangara	20	20	10	5	Line	6
XS14	1973	Yanchep	20	20	12	5	Line	6
XS15	1973	Gnangara	20	20	10	5	Line	6

[a] Mating Design

1. Open pollinated by wind on ortet
2. Haphazard, miscellaneous crosses
3. Tester, usually 4 pollen parents
4. Single pairs, without repetition of parents
5. Other controlled pollinations, some selfs.
6. Open pollinated in clone bank or seed orchard.
7. Cuttings.

TABLE 20
Tubing program carried out for progeny testing.

YEAR SOWN	NO. OF FAMILIES	NO. OF TUBES
1964	11	150
1965	23	6 880
1966	61	15 000
1967	41	15 593
1968	82	18 650
1969	97	18 550
1970	57	12 203
1971	71	11 146
1972	94	17 500
1973	114	17 822
1974	169	13 447
1975	135	13 624
1976	32	1 564
1977	77	8 000
1983	34	222

Figure 18. Types of tubes and stock containers used at Wanneroo in the early program.

Each year, prior to commencing the tubing, all frames (Fig. 19) and utensils were washed down and sterilized with formalin. The soil mix was fumigated with methyl bromide. No significant problems were associated with nutrition or disease, the seedlings being forced into growth with a liquid fertilizer, as required. For planting out, the tubes were packed in labelled carrying boxes and assembled to meet requirement for planting to the field design. Tubes were removed before planting and discarded.

Trial Layout - Trial sites were carefully selected to allow for control of variation through block layout. They were cleared and thoroughly ploughed and cultivated in the summer prior to establishment. The sites were furrow-lined by machine, immediately prior to the winter rains, to facilitate soil wetting and remove direct competition from weeds. This is normal plantation practice on the sandy sites. Field plot designs were pegged out and labelled to simplify planting of the seedlings.

Maintenance - Fertilizer was applied to the soil surface around each seedling following planting. Superphosphate was used on the grey, leached sands and super-copper-zinc fertilizer on the limestone sands. In the fifth year, trials were refertilized with superphosphate, usually broadcast at the rate of 400 kg ha^{-1}. A nitrogen-phosphorus fertilizer, broadcast at the rate of 500 kg ha^{-1}, was also applied after thinning, at age 10 to 11 years.

In the second year after planting the trial area was cross cultivated between the young trees to control competing native shrubs and weeds. Pruning was carried out to 2 m height, with secateurs at age seven years and followed up with pole saws to 5 m at age ten years and 7.5 m at age 12-13 years.

Figure 19. Nursery frames containing tubed plants at Wanneroo.

Thinning required careful supervision but was relatively straightforward. For plants in row (line) plots the poorest trees were removed (1080 to 430 stems ha^{-1}) at age approximately ten years, after measurement. At age 15-19 years the stocking of trees in the family row plots was further reduced to approximately half (430 to 215 stems ha^{-1}).

Open rooted trials (Table 21) were planted at 3 m between rows and 1.5 m between plants in rows, allowing for early culling to promote uniformity within plots. These were thinned to the best half of original plants (2240 to 1000 stems ha^{-1}) at age four years.

Damage - Several trials at more remote locations from the breeding centre (i.e. Gleneagle, Manjimup) were badly damaged by fire (XS10) or operator error (YS23, YS24). The progenies in these tests were adequately replicated in the major planting areas.

Within some trials, damage by beetles or grasshoppers after planting, or cockatoos breaking the shoots, has been severe. With adequate replication and good randomization these areas have developed to provide useful family comparisons. However, most trials had no damage.

TABLE 21

Nursery program for open rooted progeny testing and associated provenance and species trials.

YEAR SOWN	NO. OF SEEDLINGS
1965	20 640
1966	20 800
1967	11 250
1968	9 210

The success of the progeny trial program was largely attributed to their conservative design, good replication, care in establishment and location and careful supervision by the breeding team of all maintenance operations. Operations staff were made aware of the program and were interested and supportive.

For the majority of the tester trials special maintenance ceased at approximately ten years and they became available for normal logging operations. Outstanding individuals are grafted to a clone bank before special management of the area is discontinued.

Assessment - The objective of the progeny trial was to evaluate the phenotype under conditions in which the environmental effect can be assessed.

Measurements were made in January or February when shoot and cambial growth were minimal.

At age 3.5 years survivors were counted and heights measured with a height stick. This was the first expression of genetic potential and recorded the initial development of height growth. The measurement has subsequently been shown to have a high correlation with later height growth for the species.

Management prescriptions detailed another height measurement at 8.5 years when tree diameters were being measured. This requirement to calculate individual tree volumes was rarely satisfied owing to the difficulty and the time involved, especially in unthinned stands.

Diameter over bark at 1.3 m stem height was measured with a diameter tape at age 8.5 years. Stems were pruned prior to measuring diameter to facilitate the measurement (Fig. 20).

Stem form for each tree was assessed on the pruned (to 2 m) trees using set prescriptions and, whenever possible, by experienced breeding staff.

Figure 20. Early development (approximately 5 years) of a row of 10 trees for a family in a progeny trial at Gnangara plantation.

Form assessment usually followed diameter measurement when trees were about 10 m tall with a diameter of 14 cm. This provided a good test of the commercial bole length (7.5 m).

The prescription for assessment varied somewhat from a simple system in early 1960s to the procedure termed BSTAF (Appendices VIIA to VIIE). The BSTAF procedure involved a team of two visiting each tree and subjectively allocating 1 to 5 points for butt sweep (B), stem straightness (S), branch thickness (T) and branch angle (A). Points for form (F) were allocated to express apical dominance for presence or absence of forks and, or ramicorns. The BSTAF system was later modified to a 4-point system (Appendix V11E) in an endeavour to improve assessment by not having a central value.

BSTAF results were interpreted through the mean point score per family and the percentage of acceptable trees (percentage 1, 2, 3 scores) for each attribute of BSTA. For F, the percentage of non-forked stems proved to be a reliable measure for comparisons.

Wood Properties - Wood properties were not measured for local plus trees in the first stage program. Basic density and spiral grain were assessed for the selections in Portugal but were not considered in selection procedures for inclusion in the orchards. Clones with excessive spiral grain were weighted for this deficiency in culling the Mullaloo orchard.

All prospective parents in the second generation program are being sampled for wood density and this character is to be weighted in indices for selection.

Each tree worthy of selection for the second stage program had two wood cores taken, at approximately breast height, one each on the south and east sides. The cores were sampled from bark to pith and classed as mature wood in growth rings over nine years of age and juvenile wood in the rings of lesser age.

The wood cores were soaked in water for a minimum of one hour to achieve a standard saturated core volume (Smith 1954). Saturated wood volume was measured using callipers. Saturated cores were dried to 105°C for 24 hours to determine oven-dry weight.

The mean density for 468 cores of juvenile wood was 0.43 g cm^{-3} with a standard deviation (SD) of 0.03. Mean mature wood density for 418 cores from trees old enough for this determination, was 0.48 g cm^{-3} with an SD = 0.04.

Analysis - All field measurements were entered directly onto a sheet designed to aid card or tape punching for computer entry. Analysis originally presented problems owing to the limited capacity to enter data for computer analysis. With computer improvement and their increased availability these have been overcome.

Early analysis was carried out on a Concurrent mini-computer using either the FORKOV or the SPSS* statistical package. FORKOV is an analysis of variance (ANOVA) program for randomized blocks and a single covariate, provided by the Commonwealth Forest Research Institute in 1972. This program was run on CDC and Concurrent mini-computers.

Most first generation progeny trial data were analysed on a Canon SX300 computer using programs written specifically for the task. These programs were adequate for ANOVA, GCA, SCA and heritability calculations and for ranking of family means. They were, however, unable to calculate genetic and phenotypic correlations of traits or provide for the ranking of trees in index selection owing to limited memory facilities.

Height and diameter analysis presented no problems. Volume was calculated whenever height and diameter measurements were concurrent. For BSTAF measurements family mean scores were calculated and these were subject to ANOVA and ranking. The program also ranked means for the percentage of class 1 and 2 trees (plus stems) and percentage of class 1, 2 and 3 stems (acceptable crop stems). These were considered to be most useful in describing the degree of improvement achieved in stem form.

In 1988 access to a Mixed Model, Least Squares and Maximum Likelihood Program (Harvey 1988), for use on a personal computer, became available. The Harvey program is in current use.

EVALUATION AND SIGNIFICANCE OF THE TESTING PROGRAM

Comparison of Trial Results

Introduction

The major aims of the local progeny test program were:

(1) to define the best families and parental performance on the test sites;

(2) to determine the adaptability of the parental combinations to the range of sites that may be used for *P. pinaster* plantation establishment; and

(3) to provide a population and values for heritability for a second generation program.

Plantation practice with *P. pinaster* in WA focused on the Swan Coastal Plain. Two soil types have been used, both being sand dune systems (Havel 1968) with the grey sands of the inland areas (Gnangara) having undergone more leaching than the yellow sands of the coastal sites (Yanchep). Climate is relatively uniform over the area (Butcher 1986).

Progeny tests were concentrated in this area with replications of each trial on both the yellow and grey sands. Both are known to have different nutrient deficiencies and different nutrient amelioration procedures have been developed for the establishment and maintenance of plantations over the range of sites (Hopkins 1960a). These differences may favour specific genotypes and several trials were designed to demonstrate the extent of parental response to different fertilizer levels and regimes.

Increasing commercial attention to other sites in the south-west region marginal for *P. radiata* plantations, and possibly better suited to *P. pinaster*, favoured initial testing on them with improved seed.

Pedigree seed was also made available to other Australian States, New Zealand and South Africa in order to determine the adaptability of these crosses over the widest range of conditions.

Individual Trials

Measurement data, as it became available, was subject to an ANOVA to assess the efficiency of the design and the relative significance of performance of the progenies. Where progeny effects proved to be significant, family means were ranked and examined by multiple range or other tests for least significant difference (LSD).

The randomized block design used proved to be effective and the main effect for treatments (families) was significant in all trials .

A control family consisting of plants from the commercial seed in current use was included in most trials. This 'routine' control provided direct comparison of the performance of any family with that of existing plantation stock. The estimate of the improvement obtained was valuable in showing both breeding and plantation operations staff the range of gains available from the continuing program.

Individual trial results were applied as they became available and culling in the Joondalup orchard in 1974 and 1975 excluded clones E2, E14, E15 and E28 on the basis of poor performance early in the trials.

Linkage of the Trial Series

It was impossible to compare all crosses in one trial. Trials planted in any one year had to be largely opportunistic in that the families tested depended on the plants available from the pollination program. Testing had to anticipate progressive establishment, on different sites and in different years, until families of an acceptable number of breeding parents could be assessed and compared. The major requirement was to ensure that results from both individual trials and the whole planned series of trials were used most expeditiously and effectively. This was done by using a series of linkages to relate the trials to each other.

Several procedures were used to link trials. The most relevant included standard families in trials to compare the performance of all crosses on a common basis, over the variable conditions of site, cultural treatment and time.

The use of standard, linked families to assess results over a range of sites and seasonal conditions has received attention (Breese 1969; Freeman 1973; Hatcher *et al.* 1981). A major concern has been for the consistency of the performance of the selected genotypes over a range of sites, i.e. the degree to which site and genotype may interact to provide variable performance of the standards over all situations (Morgenstern 1982). To counter this several, preferably unrelated, families may be included as standards and their mean used to buffer any site-genotype interaction. The mean is then the index for gauging overall performance, and this was the purpose for which it was used in WA.

Information available indicated that the value of standard families to link trials must vary depending on the range of climates and soils tested, the species involved, the accuracy of assessment obtained for individual trials and that expected from the comparison of test results. The current program provided opportunities to examine these possibilities.

Standard Families

Five standard families were used within the trial series - S001 (E41xE2), S002 (E40xE2), S017 (E40xE41), S025 (E5xE41), S032 (E19xE40).

These were selected because of the high phenotypic evaluation of the parents, the accessibility of the clonal material and the relative ease of crossing demonstrated in early tests. Seed of each family was produced in most years as part of the pollination schedule. S002 was the most commonly used family (57 trials) while S001, S017, S025 and S032 were used in 36, 45, 32 and 25 trials respectively (Appendix IX). At least one standard family was present in 72 of the 81 trials.

Standards were included in all early trials but were excluded from the comparisons of random pair mating. Of the nine trials without standards seven are half-sib trials which incorporate either a common half-sib or routine family, as a means of cross comparing results.

Individual Family Variation - Measurements or scores for height, diameter, stem straightness and branch size for two of the standard families, S002 and S017, for all trials in which data were available, are plotted in Figure 21. The coefficients of determination for relationships between some associations of the standard families are summarized in Table 22.

Association between family performances was strong for height and diameter with from 90 to 99 per cent of variation between the two series being explained by a linear relationship. Fitted values for height and diameter growth had confidence limits (95 per cent) within 3 per cent of the mean.

The graph for straightness in Figure 21 and results in Table 22 indicated a good association which is not consistent for all families. A linear association accounted for from 70 to 89 per cent of the differences between measurements for individual standard families over the series. Results for acceptable branch size had a wider variation (34 to 73 per cent for R^2).

Variation in branching assessment was broader, possibly owing to the subjective method of assessing

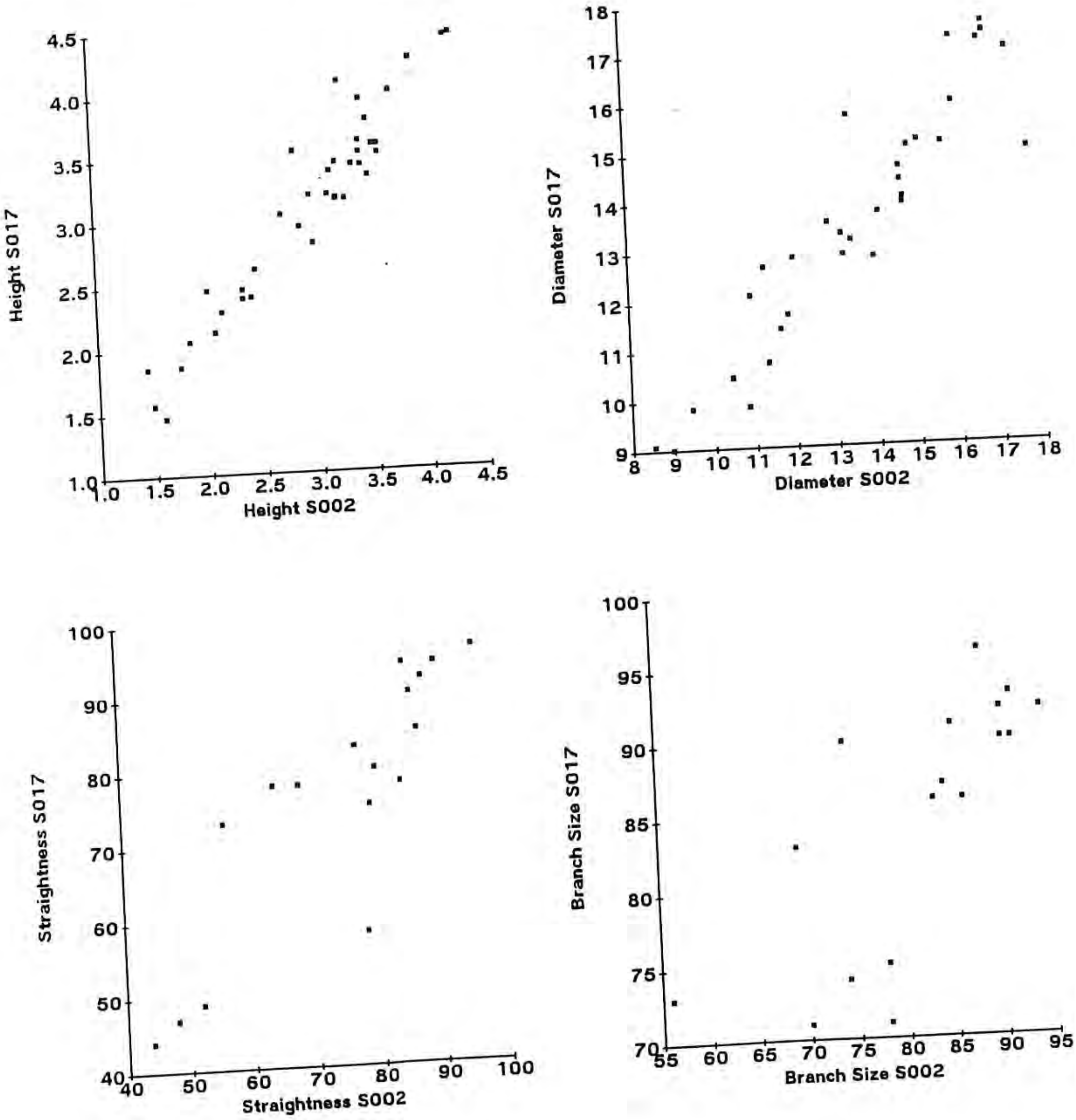

Figure 21. Associations between the two standard families, SOO2 and SO17, for height, diameter, stem straightness and branch size.

TABLE 22

Correlations between standard families for characters assessed and between individual families and the mean for standards for height (Hmn), diameter (Dmn), straight stems (Smn), branch size (Tmn), branch angle (Amn) and non forked stems (Fmn).

CHARACTER	ASSOCIATION	R^2	NO. OBSERVATIONS
Height	S002-S001	89.5	34
	S002-S017	93.2	40
	S002-S025	95.1	25
	S002-S032	90.9	19
	Hmn-S001	97.2	24
	Hmn-S002	95.9	24
	Hmn-S017	99.0	24
Diameter	S002-S001	95.0	31
	S002-S017	94.4	34
	S002-S025	94.2	23
	S002-S032	96.3	16
	Dmn-S001	98.2	12
	Dmn-S002	98.5	12
	Dmn-S017	98.7	12
Acceptable straight stems	S002-S001	74.2	21
	S002-S017	83.4	21
	S002-S025	70.0	16
	S002-S032	88.2	8
	Smn-S001	93.7	13
	Smn-S002	92.9	13
	Smn-S017	97.6	13
Acceptable branch size	002-S001	62.4	21
	S002-S017	72.6	21
	S002-S025	34.4	16
	S002-S032	54.2	9
	Tmn-S001	77.0	13
	Tmn-S002	97.4	13
	Tmn-S017	72.3	13
Acceptable branch angle	S002-S001	67.1	14
	S002-S017	72.9	18
	S002-S032	84.4	11
	Amn-S001	77.1	5
	Amn-S002	98.1	5
Normal stems	S002-S001	88.6	19
	S002-S017	81.7	17
	S002-S025	91.2	14
	Fmn-S001	93.9	11
	Fmn-S002	89.2	11
	Fmn-S017	91.1	11

BSTAF. This supposition is supported by the higher and more consistent correlations obtained for trees with normal stems (apical dominance) and for acceptable branch angle (Table 22). Straightness and these latter characters were relatively simple to assess over a range of conditions.

For the stem form and branching measurements available there was no indication of any interaction between site and genotype that may adversely influence rating of families.

Common Means for Standards - The height variation of three standard families, over the range of trials in which they were common, is displayed in Figure 22. In virtually all circumstances the difference between the least and greatest standard was less than the LSD (.05 level) calculated for all family means, i.e. the mean of the three families (Fig. 22) was not significantly different from the means of each individual family. Coefficients of determination for regressions of standards against the mean (Table 22) were 96 to 99 per cent for height and diameter and 93 to 98 per cent and 90 to 94 per cent for stem straightness and normal stems, respectively. Confidence limits for values predicted from the mean of the standards had a 95 per cent chance of being within ± 3 per cent for height and diameter, ± 4 per cent for straightness and ± 7 per cent for apical dominance.

These limits were considered to be adequate for separating the best families from the poorer performers within the program. Ranking to separate families for breeding consideration was on the basis of their deviation from the mean of the standards, together with a consideration of the LSD (.05) values in each trial.

Family performance levels (i.e. standardized scores) expressed in terms of units of standard deviation of the distribution (Hatcher *et al.* 1981) were also calculated for most test results and assisted in the rating of families across a range of trials. Generally they were found to have no advantage over comparisons based on common families.

More sophisticated procedures for estimating the average relative performance of families across the range of conditions are available. However, Cotterill *et al.* (1983) demonstrated that six methods of varying complexity ranked families of *P. radiata* in about the same order for volume and straightness. They concluded that the choice of methods is debatable. While the simpler methods are not exact they probably rank families with sufficient accuracy for most practical breeding purposes.

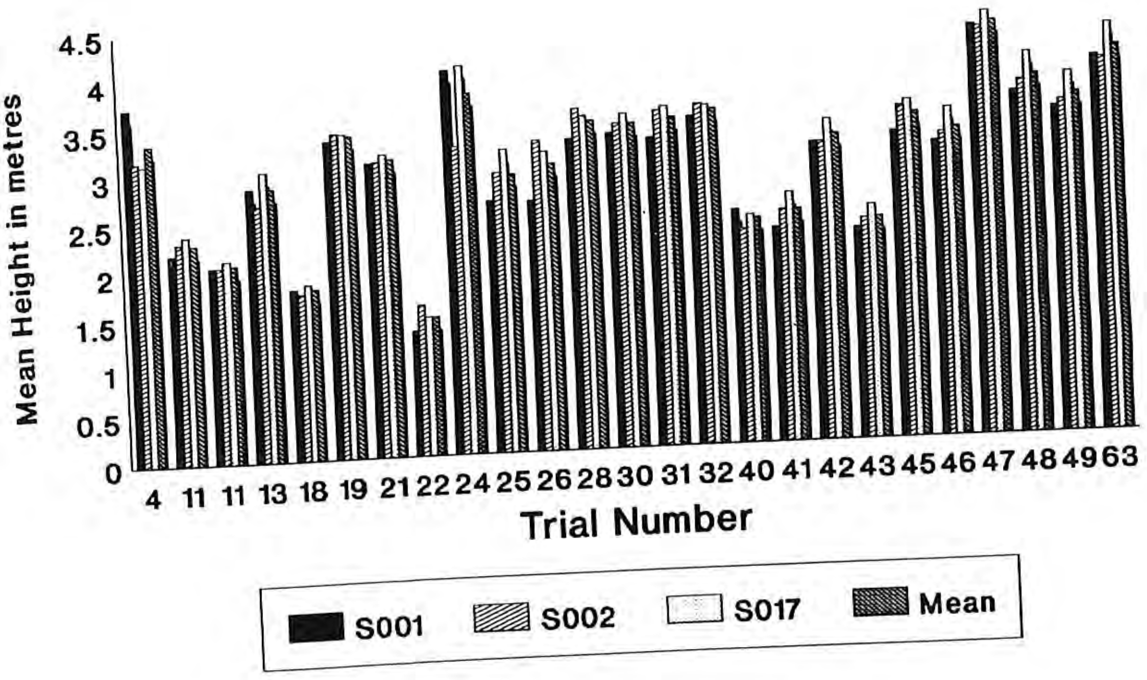

Figure 22. The relationship between individual heights for three standard families and their mean, for trials in which they are all represented.

BSTAF Comparisons

Assessment of stem and crown form (BSTAF) was subjective and likely to vary. This was exacerbated by the alteration of scoring procedures throughout the test period (Appendix VII). Although the use of mean values of BSTAF of the standard families greatly reduced variability between trials, the final decision on ranking families often had to be made on distinctions measured in individual trials.

Concern was constantly expressed during the program on the subjective nature of BSTAF assessments and the adequacy of measurements taken. Several attempts were made to improve and evaluate the system.

Point Systems - In 1972 a series of tests were carried out on trial YS05 at Mundaring. Three assessors independently classified three of the trial blocks containing 13 families. Five- and 10-point systems were used for the assessment and results were plotted to indicate the distribution of classes for different point scores and different assessors. Agreement between the three operators was very good with all distributions appearing to be normal. The 5-point system was adopted as being as effective as the more complex and time consuming, 10-point system.

Uniformity of Assessment - In 1974 two operators independently assessed Trial XS07 for form. This trial contained 39 half-sib families imported from Portugal and was planted in 1966 (Table 19). It was evaluated using the original assessment prescription for straightness, branch type and stem normality (Appendix VIIA).

Similarly in 1985 Trial YS55 (Table 19) was assessed for BSTAF by two independent teams, each of two people. A total of 1671 trees were assessed on a 4-point system (Appendix V11E).

The differences between results of the assessment for each team were analysed for significance using chi-squared procedures. All were highly significant, exceeding any reasonable probability that the two operators assessed the populations in an identical manner. Results for YS55 in Table 23 show the nature of the differences obtained for each attribute of form. Although the estimates for percentage of class 1 stems (super stems) varied greatly, the separate estimates for the percentage of good stems of final crop standard (class 1 + class 2) and poor stems (class 3 + class 4), were quite acceptable, with perhaps the exception of branch thickness.

Thus, providing interpretation is based on a mean rank score for families, or the percentage of trees of acceptable crop quality (i.e. classes 1 and 2), the differences owing to subjectivity between the teams are not important.

Interactions in Assessment - The analysis of variance of mean scores for trial XS07 separated highly significant differences for family (F), block (B) and operator (O) effects (Table 24).

For branching, the family x operator (FxO) interaction was significant, suggesting that each operator was biased in his evaluation of these traits. This interaction was not significant for apical dominance and straightness which can be assessed more directly and objectively.

The variation associated with the operators (Table 24) is an extremely small part of the total variation for the assessment of apical dominance and stem straightness. It is higher for the original single classification system for branching (Appendix VIIA) which was redefined in the assessment in YS55.

Efficiency of Assessment - Results from the independent assessments of the two trials indicated the degree of confidence that could be placed on the BSTAF data. In Table 25 results from both trials are presented to show the variation associated with families ranked on the basis of the assessments. Spearman correlation coefficients are included to show the agreement between the various ranking. In Table 25, the ranking is expressed within ± 5 per cent (± 4 ranks for 80 families), ± 10 per cent (± 8 ranks for 80 families) and ± 25 per cent (± 20 ranks for 80 families) of the true ranking. The mean of the two operator estimates was taken as the 'true value'.

The ranking of percentage of acceptable straight stems agreed with that of the mean score for straightness in XS07 ($r = 0.93$) and either expression is suitable for classifying populations. The estimate of the straightness and apical dominance of a population by a single operator can be expected to place over 95 per cent of the families within ± 25 per cent of the real value. This is also the case for branching as prescribed in BSTAF for the trial YS55. The early, compound assessment of branching in trial XS07 was considerably less satisfactory.

The ANOVA of the data for one operator in trial YS55 showed that the top 25 per cent of families were not different at the 95 per cent level of significance, indicating that the top quartile of families ranked by BSTAF can be confidently separated as the best. The overall superiority of families for form could then be based on the number of trials in which they were assessed in the top quartile.

Common Indices - The incorporation of standard families into trials provided a necessary control (covariant) to counter assessor subjectivity and the possibility of a significant interaction between family expression and block effects. The standards were assessed on the same basis as the other families and were subject to the same bias and variation. They index variability in assessments between trials and can be used to adjust for differences between measurement times or assessment crews.

Results for standard means (tmn) for S, A and F in Table 22 agreed strongly over the range of trials available for comparison. The use of the mean of standards as an index for S and F is considered to be completely satisfactory. Values for branch thickness are not as acceptable but even so, offer a useful comparison for most cases.

TABLE 23

Distributions for scores ranked by two independent operators assessing trial YS55 for butt sweep (B), straightness (S), branch size (T), branch angle (A) and apical dominance (F).

ATTRIBUTE	B		S		T		A		F	
	TEAM NUMBER AND OBSERVATIONS PER CLASS									
	Op1	Op2	Op1	Op2	Op1	Op2	Op1	Op2	Op1	Op2
Class 1	154	720	87	209	12	3	28	107	1 025	823
Class 2	1 140	678	1 177	1 114	977	847 9	86	931	549	753
Class 3	364	261	399	340	664	741	656	572	93	90
Class 4	13	12	8 8	18	80	1	61	4	5	
TOTAL	1 671	1 671	1 671	1 671	1 671	1 671	1 671	1 671	1 671	1 671
Mean	2.14	1.74	2.20	2.09	2.41	2.54	2.38	2.35	1.48	1.57
S.E	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
S.D.	0.57	0.74	0.52	0.58	0.53	0.59	0.52	0.66	0.61	0.61
Skew.	0.27	0.56	0.41	0.13	0.43	0.53	0.16	0.27	1.10	0.66
Kurt.	0.57	-.63	0.51	0.29	-.91	-.59	-1.14	0.01	0.46	-.10
Chi-squ.		500.96		56.73		58.11		111.62		54.20
%Cl 1	9	43	5	13	0.7	0.2	2	6	61	49
%Cl 1,2	77	84	76	79	60	51	61	62	94	94

TABLE 24

Analysis of variance for the assessment of 40 families in trial XS07 for straightness, branching and apical dominance, by two independent operators. Values analysed are the mean scores for 10-tree line plots for each family in each block.

SOURCE OF VARIATION	DF	APICAL DOMINANCE		STRAIGHTNESS		BRANCHING	
		MS	P	MS	P	MS	P
Family (F)	39	0.66	<0.01	0.36	<0.01	0.22	<0.01
Operator (O)	1	0.53	0.07	0.40	0.02	2.33	<0.01
Block (B)	11	1.01	<0.01	0.41	<0.01	0.74	<0.01
FxO	39	0.05	1.00	0.06	0.86	0.14	0.03
Error	869	0.16		0.08		0.10	
TOTAL	959	0.19		0.09		0.12	

TABLE 25

Correlation and accuracy obtained for rankings of attributes for straightness, branching and apical dominance in trials XS07 and YS55. Forty and eighty-one families respectively, were assessed independently by two Operators (R1 and R2). Results are compared for Plus Stems, Acceptable Stems the Mean Rank Score and the calculated True Mean.

RANKING COMPARISON		TRIAL No.	PERCENTAGE DIFFERING BY <			SPEARMAN r_s
			5%	10%	25%	
			STRAIGHTNESS			
R1 Plus	R2 Plus	XS07	20.0	35.0	65.0	0.46
R1 Accep	R2 Accep	XS07	32.5	40.0	72.5	0.67
R1 Mscore	R2 Mscore	XS07	35.0	50.0	77.5	0.70
R1 Mscore	R2 Mscore	YS55	30.9	45.7	76.5	0.72
R1 Plus	Mean plus	XS07	32.5	55.0	87.5	0.83
R1 Accep	Mean accep	XS07	32.5	62.5	92.5	0.90
R1 Mscore	Mean score	XS07	50.0	67.5	95.0	0.91
Mean plus	Mean accep	XS07	12.5	22.5	62.5	0.63
R1 Mscore	Mean score	YS55	46.9	67.9	95.1	0.92
Mean plus	Mean score	XS07	12.5	25.0	65.0	0.74
Mean acc	Mean score	XS07	47.5	70.0	95.0	0.93
			BRANCHING			
R1 Branch	R2 Branch	XS07	25.0	30.0	47.5	0.18
R2 Branch	Mean brch	XS07	30.0	52.5	82.5	0.78
			APICAL DOMINANCE			
R1 Form	R2 Form	XS07	32.5	47.5	85.0	0.86
R1 Form	Mean form	XS07	45.0	70.0	100.0	0.95
R1 Form	R2 form	YS55	25.9	58.0	76.5	0.72
R1 Form	Mean form	YS55	40.7	59.2	97.3	0.92
			BRANCH THICKNESS			
R1 Branch	R2 Branch	YS55	30.9	45.7	71.6	0.71
R1 Branch	Mean brch	YS55	39.5	67.9	97.5	0.93
			BRANCH ANGLE			
R1 Angle	R2 Angle	YS55	42.0	56.8	86.4	0.84
R1 Angle	Mean angle	YS55	55.5	80.2	97.5	0.95
			BUTT SWEEP			
R1 Sweep	R2 Sweep	YS55	18.5	38.2	76.5	0.68
R1 Sweep	Mean sweep	YS55	40.7	64.2	95.1	0.91

Conclusions - BSTAF data were subjective and susceptible to interaction between the operators and the trial families. Standard families, incorporated in trials, helped to adjust for this bias in assessment. Operator bias can cause large differences in the scores for attributes of form which are associated with extreme variation. Percentage of plus stems is such an instance. Means for acceptable stems and mean family scores were suitable for ranking on butt sweep, stem straightness, branch angle and apical dominance. Assessment of branch size was the least satisfactory but it was adequate for first generation selection.

For second generation selection, a relatively rapid BSTAF system should be used, ensuring during the assessment that the full scale is being used to rank individuals. This is now relatively simple with the aid of a portable field computer to directly record the assessment scores and display the nature of the frequency distribution, as required, during the assessment. TBIMS (Butcher 1993) integrates this data and the best families can then be identified. Superior individuals may then be validated on the basis of visual inspections with measurement of branch and stem diameters, if necessary.

Genotype-Environmental Interactions

Introduction

Genotype-environment interaction (GEI) is the terminology used to describe situations where there is a change in the relative performance of a given genotype when grown in different environments, i.e. if some families are better or worse under different environmental conditions.

Major attempts to define the extent of GEI in the program were made to:

1 assess whether a single orchard could produce acceptable commercial seed for plantations in the State and whether a single breeding population would suffice;

2 assess the significance of interaction in progeny tests and how it should effect the interpretation of results for main effects;

3 assess the minimum number of sites and types of site required to test progeny within the State;

4 assess the scope for greatly improved genetic performance by directing specific genotypes to specific localities.

Early results on both the yellow and grey sands north of Perth indicated that the same families were best or worst in early height growth on both sites and it appeared that GEI had little importance to the program. Trials planted in 1968 and 1969 were located over a range of potential plantation sites dispersed throughout the south-west of the State (Table 19) to determine the significance of GEI.

Early 1968 Results

Butcher (1974) presented results for early height growth of families in the 1968 trials at Gnangara, Yanchep, Mundaring, Hamel, Collie and Pemberton. The sites covered a rainfall range of 810 to 1260 mm, an elevation range from 60 m to 300 m above sea level and soils varying from phosphate deficient sands to fertile, deep red, basic, loamy sands.

Height growth at age 3.5 years was significantly different within sites and between sites. However, the same families had similar ranking on the different sites.

Results were examined by the regression method of analysis described by Finlay and Wilkinson (1963). Linear regressions were calculated for the height of individual families against the mean height for the 36 families concerned, at each block or site.

The regression coefficient is a measure of the adaptability of the genotype (Fig. 23) and the correlation coefficient, reflecting the scatter of points about the regression line, is a measure of the stability of genotypic response (Bilbro and Ray 1976). A regression coefficient of 1 reflects average adaptability and a coefficient appreciably different from 1 reflects relative lack of capacity for a coordinated genotypic response to change in site quality. Similarly a coefficient of determination (R^2) of 1 reflects complete stability of response whereas a coefficient much less than 1 shows instability over a range of sites (Sluder 1980; St Clair and Kleinschmit 1986).

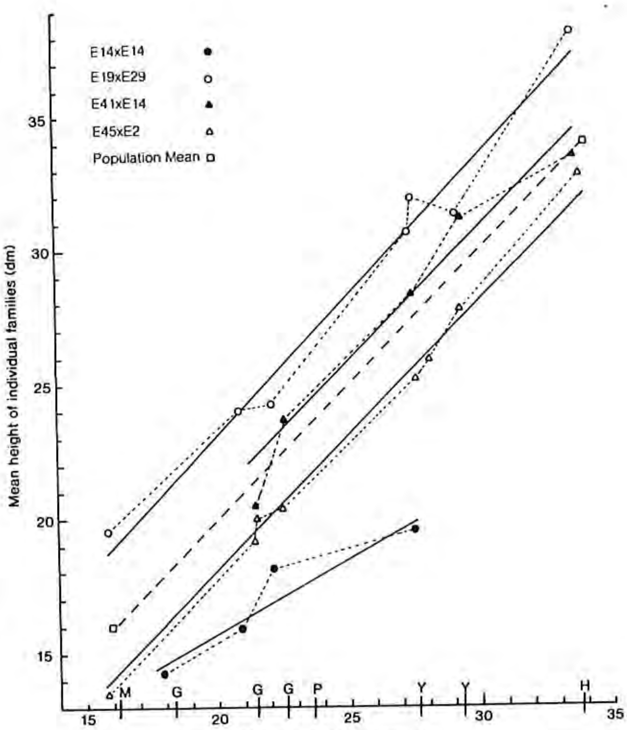

Figure 23. Regressions of the site x genotype interaction for trial families planted in 1968, illustrating adaptability and stability over the site range Mundaring (M), Gnangara (G), Pinjar (P), Yanchep (Y) and Harvey (H).

Twenty-seven of the 36 families investigated by Butcher had a regression coefficient (b) in the range 0.85 to 1.15. Figure 23 shows family E19xE29 (b = 1.05) to have average adaptability producing above average height growth while family E45xE2 (b = 1.04), also a family of average adaptability, was low yielding over the range of sites tested.

The selfed family of parent E14 had the smallest regression coefficient (b = 0.54). Although above average in stability (Finlay and Wilkinson 1963) the family was relatively unresponsive in height growth to improvement in environmental conditions. Inbreeding depression was associated with below average height growth at the site of lowest potential (Gnangara) and the family made little additional growth on the highest quality site.

Later Results for the 1968 Series

The 1968 trials were measured at a later age to investigate whether the associations changed with age and their relevance to volume growth.

The trials YS11, YS13 and YS17 planted at Gnangara, Yanchep and Harvey (Hamel) respectively, were analysed for height at 3.5 years, height at 4.5 years, height increment and volume at 7.5 years of age. The series had 8 families representing 4 female parents (E19, E28, E40, E41) crossed with 2 male parents (E14, E29), in common.

Height and Volume Growth - Initial analyses for height and volume growth for site x family interactions were not significant. On partitioning the variation to examine genotypes (Table 26) the site x female interaction was found to be significant (0.05 level). Ratios of the variances of the interaction to the female genotype were 18.2 and 45.3 per cent for height and volume, respectively.

Figure 24 shows the nature of the interaction. Volume production of female parent E41, which altered from lowest on the poorest site at Gnangara to the highest on the intermediate site at Yanchep, tended to decrease from the intermediate site at Yanchep to the most fertile, Hamel site. E19, however, showed superiority on the poorest (G) and most fertile (H) sites but average performance on the intermediate (Y) site at Yanchep. However, the interactions were a very small part of the total variation, being 1.4 and 2.6 per cent for height and volume, respectively.

The regression coefficients and the coefficients of determination for height and volume growth (Table 27) showed general good adaptability and stability for all parents. Parent E41 (b = 1.09) showed most favourable adaptation to improving site conditions with good stability. The E28 genotype with below average site adaptability (b = 0.83) was discarded from the orchard program on the basis of early trial data.

Parental Comparisons in the 1969 Trials

Trials YS18, YS19, YS23 and YS25 planted in 1969 incorporated 15 common families at Gnangara, Yanchep, Manjimup and Hamel, respectively. Each of five female parents (E31, E46, E49, E50, E53) were crossed with each of three male pollens (E14, E33, E40), providing the opportunity for analysis as a factorial and an improved examination of parental effects. Butcher (1976) commented on the analysis of families showing that the ratio of the site x family interaction to the family main effect was 30 per cent.

Results - Results of the ANOVA for height growth at age 3.5 years are shown in Table 28.

Interaction between environment and the female genotype was significant at the 0.01 level and that between environment and male genotype was significant at the 0.05 level.

The ratio of variances of the interaction to the relative genotype was 16.5 per cent for the female and 45.9 per cent for the male. Shelbourne (1972) suggested that if (G x S)/G approached 50 per cent then the effects of the GEI were likely to be serious on gains from selection and testing. On this basis the site x male interaction could be important to the selection program. It could be worthwhile to select genotypes for the particular sites.

The interactions for female and male parents accounted for 1.2 and 0.6 per cent of the total variation, respectively.

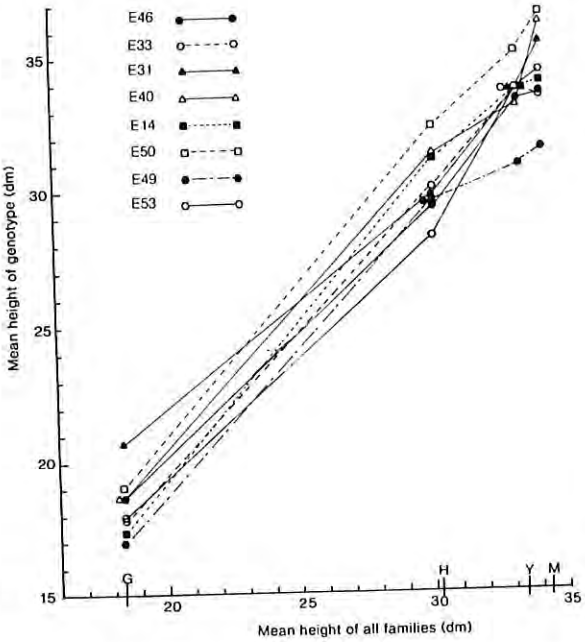

Figure 24. Site x genotype association for volume at age 8.5 years, in trials planted in 1968 at Gnangara (G), Yanchep (Y) and Hamel (H).

TABLE 26

Analysis of variance for height at 4.5 years and volume at 7.5 years for common families planted in 1968 at Gnangara, Yanchep and Hamel.

		HEIGHT (m)			VOLUME[a] (m^3)		
SOURCE OF VARIATION	DF	SUM OF SQUARES	V.R.	SIGNIFICANCE	SUM OF SQUARES	V.R.	SIGNIFICANCE
Site (S)	2	761 933	314.07	0.01	3 048 784	18.19	0.01
Block (site)	18	77 473	3.55	0.01	1 508 345	6.88	0.01
Family	7	88 774	10.46	0.01	225 323	2.56	0.02
Female (F)	3	44 011	12.09	0.01	195 247	5.34	0.01
Male (M)	1	44 265	36.49	0.01	4 536	0.37	0.54
F x M	3	498	0.14	ns	45 527	0.70	0.56
S x Family	14	18 502	1.09	ns	230 664	1.31	0.21
S x F	6	16 002	2.20	0.05	176 865	2.42	0.03
S x M	2	2 500	1.03	ns	29 196	1.20	0.31
S x F x M	6	5 918	0.81	ns	-		ns
Residual	126	152 857	-	-	1 608 643	-	-
TOTAL	167	1105 457	-	-	6 597 144	-	-

[a] Volume expressed as mean tree X 1000 m^3

TABLE 27

Regression coefficients and correlation coefficients calculated for the mean for each parent for each block against the mean for all families in each block. Data relate to families planted in 1968 at Gnangara, Yanchep and Hamel.

	HEIGHT		VOLUME	
PARENT	B	R	B	R
E14	0.99	0.99	1.07	0.97
E29	0.99	0.99	0.92	0.96
E19	1.07	0.97	0.99	0.92
E40	0.94	0.95	1.02	0.91
E41	1.09	0.97	1.11	0.96
E28	0.83	0.93	0.87	0.89
Number	21		21	

TABLE 28

Analysis of variance for height at 3.5 years of age for 1969 plantings of families common to Gnangara, Yanchep, Manjimup and Hamel.

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SQUARE	V.R.	SIGNIFICANCE
Site (S)	3	2408 935	802 978	553.01	0.01
Block (Site)	27	137 775	5 102	3.51	0.01
Female (F)	4	85 222	21 306	14.67	0.01
Male (M)	2	16 315	8 158	5.62	0.01
F x M	8	19 306	2 413	1.66	ns
S x F	12	42 162	3 514	2.42	0.01
S x M	6	22 470	3 745	2.58	0.05
S x F x M	24	53 428	2 226	1.53	ns
Residual	504	732 029	1 452	-	-
TOTAL	599	3517 642	-	-	-

TABLE 29

Analysis of variance of diameter measurement at age 8 years for trials YS49 at Gnangara and YS50 at Busselton.

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SQUARE	VARIANCE RATIO	SIGNIFICANCE
Site (S)	1	351.112	351.112	26.15	0.001
Block (Site)	16	214.834	13.427	5.60	0.001
Families	19	99.585	5.241	2.19	0.003
Female (F)	4	25.812	6.453	2.69	0.031
Male (M)	3	28.501	9.500	3.96	0.009
F x M	12	45.272	3.773	1.57	0.098
S x Families	19	69.757	3.671	1.53	0.073
S x F	4	28.950	7.238	3.02	0.018
S x M	3	9.736	3.245	1.35	0.257
S x F x M	12	31.071	2.589	1.08	0.376
Residual	304	728.411	2.396	-	-
TOTAL	359	1463.700	-	-	-

The interactions, plotted in Figure 25, showed very little deviation from a straight line relationship for each parent. The slope of the regressions (b range from 0.89 to 1.09) indicated good adaptability and the standard deviations suggested that stability was acceptable (Breese 1969).

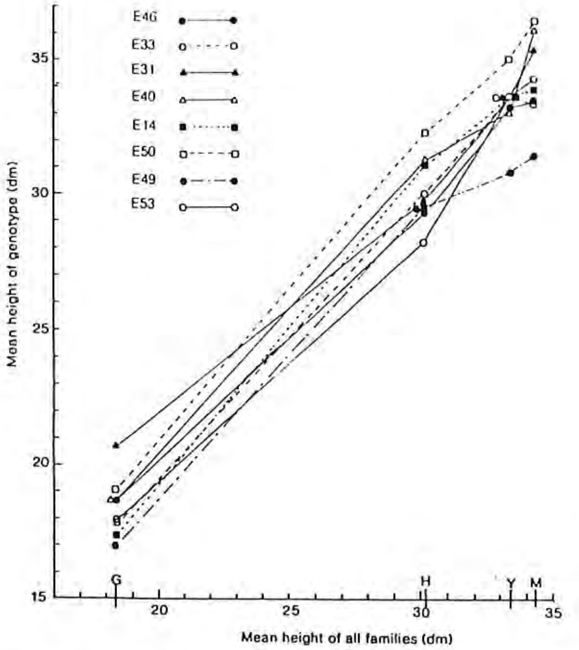

Figure 25. Plot of the interaction in height growth between genotype and site in tests planted in 1969 at Gnangara (G), Hamel (H), Yanchep (Y) and Manjimup (M).

These tests covered a wide range of sites from very poor at Gnangara to excellent at Yanchep and Manjimup (Fig. 25). Differences between means for environment at Gnangara and Hamel, and Hamel and Yanchep were highly significant (0.001 level). The difference between environmental means at Manjimup and Yanchep was not significant.

Ranking the means for the 15 families and eight parents involved (Appendix X) placed the three best families among the best at each site and the three poorest families among the worst at each site (Butcher 1976). Again the interaction does not seem to be relevant to the practical breeding program.

Trials YS49 and YS50

Trials YS49 and YS50 were the largest established, having 80 common families of 5-tree units, within ten replications as randomized blocks. They were located at Gnangara and Busselton respectively and were planted in 1974. The trials included some crossings with imported parents and provided for the comparison of five female parents (E28, E40, E45, E49, E53) with four male parents (E15, E34, E154, E182) in a balanced design with nine replications.

Analysis of diameter, measured at age eight years, allowed for a comprehensive investigation of the nature of parental (genotype) interactions. It also provided a check on the effectiveness of the trial design as the large number of families and 5-tree unit plots resulted in large blocks.

Results - Within the analysis, the family variation was partitioned into female and male main effects and a male x female interaction term (Table 29). Female means differed significantly at the 0.05 level and male means at the 0.01 level. The interaction term between genotypes was not significant at the 0.05 level.

The site x female interaction was significant, the ratio of variances of site x female to female genotype being 112 per cent. This interaction is demonstrated in Figure 26. Female parents E28 and E53 show poorest adaptability and relatively little growth response to improved site potential. This is contrary to E49 and E40 which favour the better site.

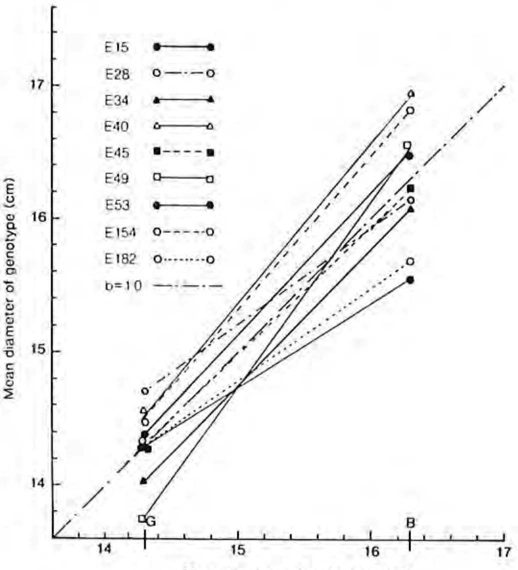

Figure 26. Site x genotype interaction for diameter at age 8 years in trials YS49 and YS50.

Discussion - The ANOVA (Table 29) detected a site x family interaction, significant at the 0.07 level, which accounts for 4.8 per cent of the total variation.

In practice this result would normally be considered unimportant and disregarded. Examination of the parental variances suggest, however, that the interaction was in fact biologically important. The high ratio of the interaction variance to the female genotype variance of 112 per cent was well in excess of the 50 per cent value suggested as worthy of consideration for selection purposes (Shelbourne 1972). It should be noted that this ratio for the family and family x site variances (69.9 per cent) also exceeded the suggested threshold and is, perhaps, more relevant in indicating the importance of the interaction than the F value. Examination for significant interactions by procedures other than the standard F ratios is available from factorial designs and possibly in this case is warranted (Freeman 1973; Mize and Schultz 1985).

On the assumption that the regression b values indicate adaptability, the range encountered was from 0.43

TABLE 30

Regression values for families and parents in trials YS49 and YS50. Each regression is for the mean for the family in each block against the mean diameter for all families in that block. Eighteen observations were available for each regression.

FAMILY OR PARENT	COEFFICIENT B	STANDARD DEVIATION	R^2
E28xE15	0.64	0.21	37.2
E28xE34	0.77	0.19	50.2
E28xE154	1.03	0.27	48.0
E28xE182	1.24	0.44	33.6
E40xE15	0.78	0.26	35.5
E40xE34	0.99	0.23	50.9
E40xE154	1.65	0.36	57.2
E40xE182	0.76	0.22	43.5
E45xE15	1.40	0.28	61.1
E45xE34	0.78	0.20	49.1
E45xE154	1.15	0.30	48.8
E45xE182	0.59	0.26	24.4
E49xE15	1.31	0.27	59.1
E49xE34	1.67	0.24	74.8
E49xE154	1.03	0.34	36.3
E49xE18	1.48	0.29	61.8
E53xE15	0.79	0.30	30.0
E53xE34	0.95	0.30	37.9
E53xE154	0.43	0.38	7.5
E53xE182	0.57	0.20	34.3
E28(F)	0.92	0.14	73.4
E40(F)	1.04	0.14	77.0
E45(F)	0.98	0.14	76.7
E49(F)	1.37	0.10	92.2
E53(F)	0.69	0.13	64.7
E15(M)	0.99	0.12	81.6
E34(M)	1.03	0.09	89.7
E154(M)	1.06	0.13	79.8
E182(M)	0.93	0.13	76.1

M = Male
F = Female

for family E53xE154 to 1.48 for family E49xE182 (Table 30). An examination of the parental main effects showed E53 to have the poorest adaptability with a b value of 0.69. Parent E49 had a b value of 1.37 showing a great efficiency in using the better site.

However, any practical interpretation of interaction effects need to be viewed cautiously. In the wider ranging 1969 trials, parents E53 and E49 had regression coefficients of 1.03 and 1.06 respectively, indicating similar and average adaptability; standard deviations for the coefficients were both relatively large.

Although comparable within themselves, the R^2 values and standard deviations in Table 30 appear to reflect relatively poor uniformity in the randomized block design through using excessively large blocks. It is possible that excessive variation resulting from inadequate design has influenced interaction effects.

Interactions Associated with Provenance

In 1974, three trials - YS51, YS52 and YS53 - were planted at Gnangara, Yanchep and Busselton with 28 common families. These consisted of crosses of local Leirian plus parents with selected parents of the Leirian,

TABLE 31

ANOVA for diameter at age 8 years for inter provenance crosses in Trials YS51, 52 and 53. Analysis is for full-sib families and for three provenance groups Leiria x Leiria (ExE), Leiria x Landes (ExL) and Leiria x Corsican (ExC).

SOURCE OF VARIATION	DF	MEAN SQUARE	VARIANCE RATIO	SIGNIFICANCE
		FULL-SIB FAMILIES		
Site	2	350.001	30.39	0.001
Block (Site)	27	11.515	10.57	0.001
Families	23	12.989	11.93	0.001
SitexFamilies	46	2.150	1.94	0.001
Error	621	1.089	-	-
TOTAL	719	-	-	-
		PROVENANCE GROUPS		
Site	2	350.001	30.39	0.001
Block (Site)	27	11.515	9.50	0.001
Provenance	2	104.588	86.26	0.001
Site x Provenance	4	8.838	7.29	0.001
Error	684	1.213	-	-
TOTAL	719	-	-	-

Landes and Corsican provenances growing in WA. The objective was to explore the potential for improvement by inter-provenance crossing. The study demonstrated the dominant transmission of certain characters from different provenance populations as well as the interaction of provenance with site (Hopkins and Butcher 1993).

The trials showed the extent of the local capacity in WA for GEI in families containing near maximum variation in the species.

Stem diameters at age eight years for eight family crosses for each provenance group, common to each trial, were separately analysed both as families and as three separate provenance groups (Table 31). Site x family and site x provenance interactions were highly significant (0.001 level).

The Leiria x Leiria (ExE) group had better diameter growth (0.01 level) than the Leiria x Landes (ExL) and the Leiria x Corsican (ExC) groups at Yanchep and Gnangara (Fig. 27). At Busselton it was still significantly better than the other groups but only at the 0.05 level. The ExL group was superior to the ExC group at Yanchep and Gnangara but did not differ significantly (0.05 level) at Busselton.

Discussion - The site x family interaction accounted for 4.7 per cent of the total variation. The ratio of (site x family)/family variances was 16 per cent.

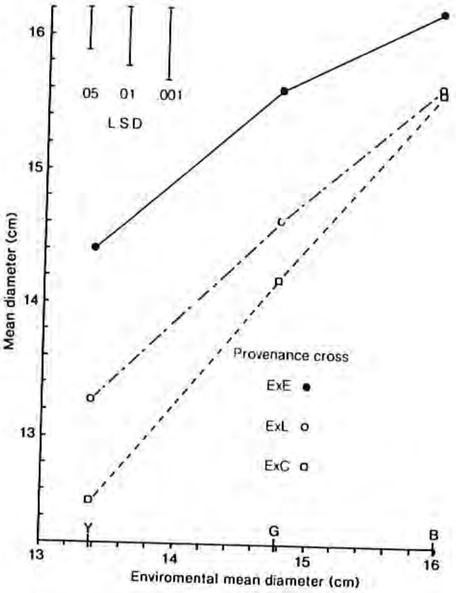

Figure 27. The site x provenance interaction obtained in trials YS51, YS52 and YS53 for provenance crosses between Portuguese (ExE), Portuguese and Landes (ExL) and Portuguese and Corsican (ExC) clones. The trials were located at Yanchep (Y), Gnangara (G) and Busselton (B).

TABLE 32

Fertilizer treatments for trials YS35 and YS36.
Amounts are in kilograms per hectare and refer to superphosphate for P and ammonium sulphate for N.
Applications in 1971 and 1973 were spot;
the remainder were broadcast.

FERTILIZER			1971 YEAR 0		1973 YEAR 2		1975 YEAR 4		1977 YEAR 6		1979 YEAR 8		1983 YEAR 12	
Code	P	N	P	N	P	N	P	N	P	N	P	N	P	N
1	P1	N0	57	-	-	-	-	-	200	-	200	-	-	-
2	P1	N1	57	-	-	-	-	100	200	100	200	100	-	100
3	P2	N0	57	-	-	-	200	-	-	-	-	-	200	-
4	P2	N1	57	-	-	-	200	100	-	100	-	100	200	100
5	P3	N0	57	-	57	-	200	-	200	-	200	-	200	-
6	P3	N1	57	-	57	-	200	100	200	100	200	100	200	100

Data in Figure 27 suggest that the Corsican and possibly the Landes influences have greater expression under cooler, wetter climates of Gnangara and Busselton. This would support results obtained in provenance testing of the species in France (Alazard 1982) and New Zealand (Sweet and Thulin 1962).

From analysis of the impacts of the separate provenance impacts (Fig. 27) it can be seen that the use of any one provenance group alone provides good adaptation. The site x provenance interaction accounted for only 1.7 per cent of the total variation and the planting of any one provenance alone promises insignificant non-additive effects. The local program has concentrated purely on the Leirian provenance and the interaction with site, as demonstrated over the range tested, is of minor importance.

Genotypic Response to Fertilizers

On most sites on the Swan Coastal Plain effective plantations of *P. pinaster* can only be established and maintained with the addition of artificial fertilizers (Hopkins 1960a; Butcher 1977b). Progeny tests were normally given the fertilizer treatment that was standard for plantation operations on that site type.

Two trials (YS35 and YS36) were planted in 1971 to examine the extent and nature of variation that may be expected from fertilizers in genotype testing procedures. Trial YS35 was planted at Gnangara and trial YS36 at Pinjar on grey sands.

Procedure - Trial YS35 incorporated three female genotypes (E19, E40, E46) crossed with each of five males (E29, E33, E41, E154, E182). The 15 families were planted as single-tree units randomized to give 15 tree subplots. There were six subplots randomized within each 90-tree plot. Overall there were four blocks and each contained six plots.

Six fertilizer treatments were randomly allocated to the plots in each block. These consisted of three different levels of superphosphate (P) and three different levels of ammonium sulphate (N) fertilizer additions (Table 32).

Trial YS36 was modified to provide a balanced design with four male genotypes (E29, E33, E145, E182) as there were insufficient seedlings of the E41 genotype.

Both trials were planned as factorials with six single-tree plots of each family randomized within each block. Mortalities have resulted with development and to provide a consistent record of results over time, the trials have been analysed as complete randomized block experiments. The means of the survivors of the initial six plants of each family in each block were analysed.

Significance of main effects and interactions with development of the trial is shown in Table 33. The results are summarized in Figures 28 and 29.

Responses to fertilizer by families and parents were significant but there were also significant interactions.

Interactions - A highly significant male x female interaction in YS35 (Table 33) was associated with crosses of E46 with E41 and E182 (Fig. 28). In Trial YS36, which does not include E41, this interaction is not significant (Fig. 28, Table 33).

TABLE 33

Significance of treatments and interactions for diameter data in trials YS36 and YS35 for measurements in years 1980, 1983 and 1987.

SOURCE OF VARIATION	PROBABILITY FOR F RATIO					
	TRIAL YS35			TRIAL YS36		
	1980	1983	1987	1980	1983	1987
				FAMILIES		
Block	.001	.001	.001	.001	.001	.001
Fertilizer	.001	.003	.047	.001	.001	.001
Family	.001	.001	.004	.029	.005	.001
Fert. x Family	.906	.483	.443	.105	.250	.355
				GENOTYPES		
Female (F)	.003	.065	.224	.029	.006	.003
Male (M)	.001	.001	.001	.010	.002	.001
F X M	.001	.001	.001	.807	.906	.728
Fert. X F	.821	.602	.606	.725	.749	.738
Fert. X M	.784	.607	.550	.068	.056	.083
Fert. X F X M	.767	.319	.302	.475	.422	.542

The fertilizer x male interaction in trial YS36 was consistent within trial development and marginally significant (.06 level or less). The trend lines plotted in Figure 29 indicated that E29 may have been adversely affected by nitrogenous fertilizer additions, in the presence of P, at medium to high levels (Treatments 4 and 6) while E182 was adversely affected by nitrogen at low to medium levels (Treatments 2 and 4). The other genotypes increased response with N addition to P. This was still present in the 1987 measurement (Table 33) following the further addition of fertilizers (Table 32). In Figure 29 the non-significant interaction in trial YS35 is plotted for comparison. E29 again showed a slightly negative response to N addition in treatment 4 but otherwise all genotypes had a positive response to nitrogen additions to a phosphatic base.

Family x fertilizer interactions studied for *P. radiata* in South Australia (Boomsma *et al.* 1981) showed that high levels of significance were common. However, the proportion of the total variation involved in the interaction and the ratio of the interaction variance to the genetic variation were small and considered to be within acceptable limits. The current trials with *P. pinaster* showed that genotype x fertilizer interactions were similarly unimportant within the context of the improvement program.

Within the scale of the trials it is considered that the male x fertilizer interaction can be ignored for the improvement program.

Magnitude of the Interactions

The 1968 and 1969 trials covered a full range of sites for the species. Trials YS49 and YS50 compared a wide range of local and imported genotypes on two extreme sites. Trials YS51, YS52 and YS53 compared main provenance groups over the site range, and YS35 and YS36 tested genotype response to extremes of fertilizer use. The results from them indicate that trial design, maintenance and measurement were sufficiently sensitive to most interactions. These, associated with genotypes, do need to be recognized in the analysis of trial results but, with one or two possible exceptions, the magnitude of the interactions identified was too low to have any important bearing on selection of genotypes on the basis of results for main effects. Knowledge of participation by a parent in an interaction may guide the final decision as to which families are to be included in a breeding program where it is required to restrict the number of parents to a workable minimum.

External Testing

Full-sib families from the program were supplied to other breeding centres in Australia, New Zealand and South Africa for testing (Appendix XI). Results received from some of these trials provided a wider view of the nature of GEI in the improved Leirian seed lots and of the adaptability of the seed orchard material produced in WA (Butcher 1976).

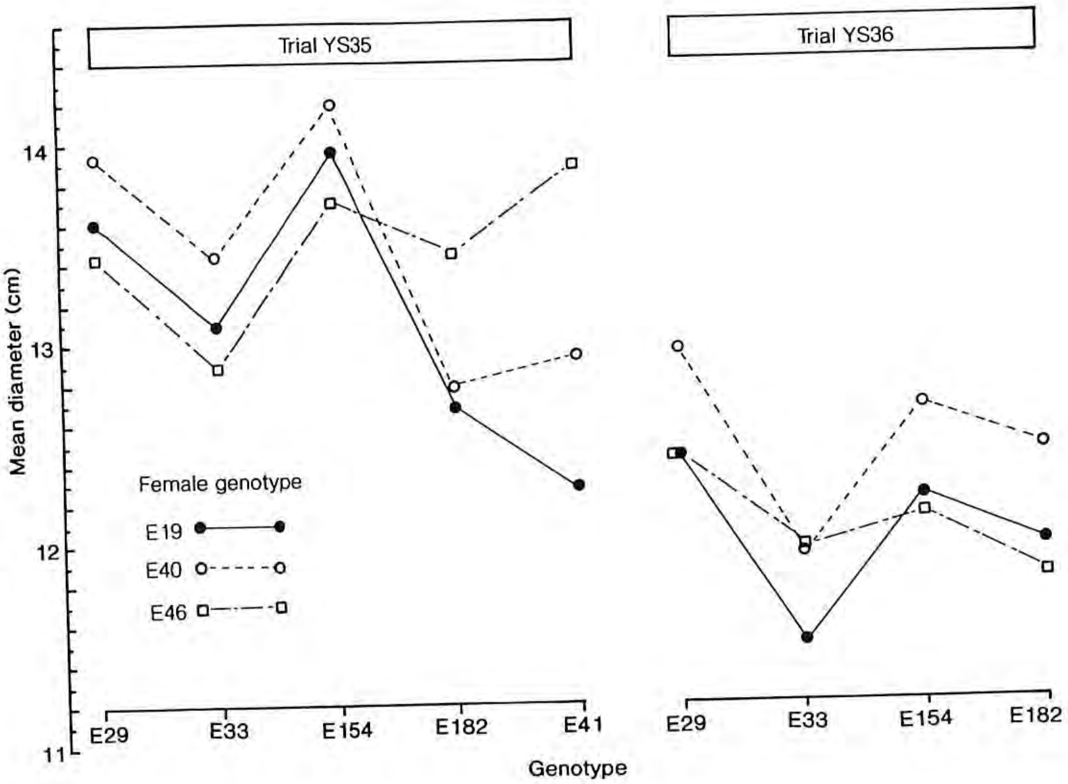

Figure 28. Interaction between female and male genotypes for diameter development in trials YS35 and YS36. The interaction for YS35 was highly significant (.001 level) while that for YS36 was not significant.

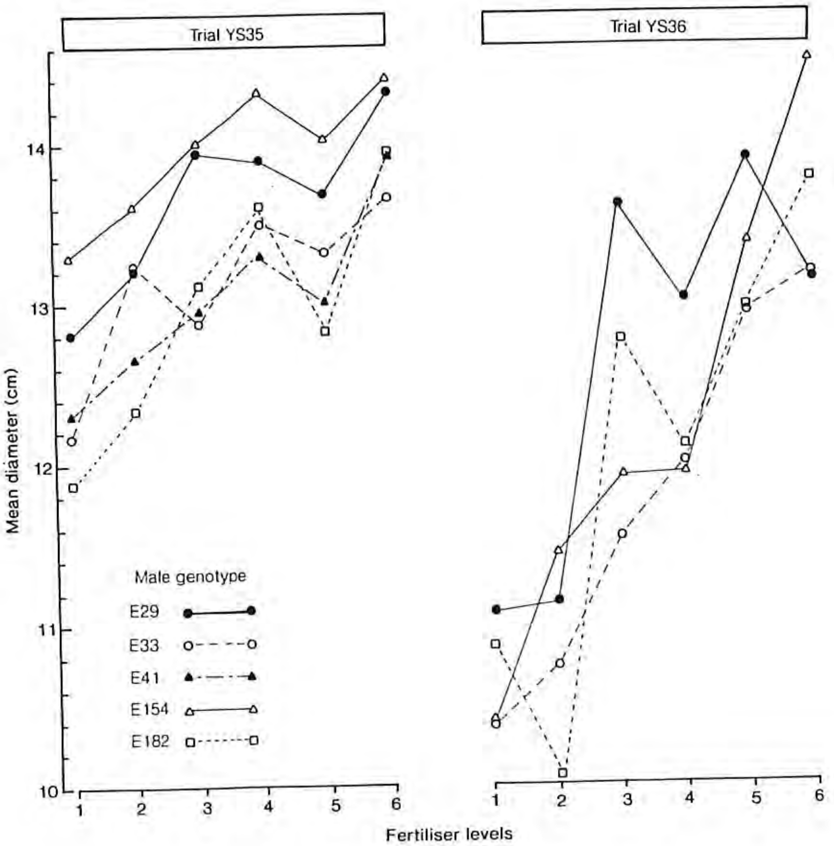

Figure 29. Interaction between fertilizer treaments and the male genotypes in trials YS35 and YS36. The relationship in YS35 was not significant while that in YS36 was significant at the 0.06 level.

Results - Mean heights for nine families tested on four sites in WA and two sites in Victoria are ranked in Table 34. Ranking was on the basis of the mean performance of each family at each site. The differences between families in the Gnangara and Mowat tests were not significant.

Similarly, in Table 35, a further six families planted in South Africa and on a Victorian site are ranked on the measured means. Again the family differences for the Gnangara data were not significant in the ANOVA and there was little basis for the ranking.

Interactions between locations and families for a composite ANOVA for all sites were significant for both data sets. The ratios between location x family and family variances were 0.36 for data in Table 34 and 0.96 for data in Table 35.

Discussion - The high ratio of location x family to family variances of 0.96 for families in South Africa, Victoria and WA support some WA results to show that there may be a GEI effect for the species.

Deletion of the two sets of families in which statistical tests could not identify significant family differences (Table 34) provided for concordance of ranking at the 0.05 level. This practice would normally be acceptable. It was concluded that there was insufficient evidence to suggest that GEI was significant.

GEI restricts the use of ranking of families to ascertain priority for specific site conditions, unless the significance of difference between means and the knowledge of interactions and their nature is appreciated.

Matheson and Raymond (1984), investigating the importance of site x genotype interactions for *P. radiata*, rejected the concept of selecting specific localities to best use families for breeding. Homogeneous regions within which interaction was absent could not be identified. They recommended that the most suitable alternative was to identify the clones whose progeny contribute most to interactions and to delete these parents from the breeding program. This approach also appears to be relevant for *P. pinaster* for the Leirian population improvement within WA.

Conclusions from Evaluation of the Trial Series

Trial design, maintenance and measurement within the program were sufficient to provide all data required in the objectives for progeny testing in the first generation program. Hindsight and knowledge of the variances now allow greater economy in the use of unit plot sizes, number of blocks and replications of trials in future work.

GEI - Trials were sufficiently sensitive to reveal that interaction between genotypes and between genotype and site is commonplace for the species. Within the WA situation the approach to interactions is simplified by the sole use of the Leirian provenance which shows superior growth on all sites tested.

Detailed examination of interactions using factorial and regression procedures has shown that GEI is relatively unimportant in the selection process. The proportion of total variation associated with interaction was usually minimal and the ratio of interaction to the genotypic main effect was within the bounds considered acceptable. In particular, trend diagrams of the interactions were most useful in rapidly and clearly indicating their importance within the magnitude and range of values.

The standard testing procedure of replicating trials on major sites and considering all trials in family selection, compensates for interaction effects in individual trials.

Limited data from the performance of families in Victoria and South Africa indicate that the families performing best locally will produce seed of high quality for all areas which favour the Leirian provenance.

Stem Form - A major emphasis has been placed on straight stems and small, wide angled branches within the improvement aims. Concerns over the adequacy of subjective procedures for assessment of these characteristics were unimportant in the first generation program. Irrespective of the assessor, the percentage of good stems was distinguished from the percentage of poor stems in the BSTAF assessment.

The use of standard families in trials to index any bias in assessment and the use of skilled assessors assists to overcome major difficulties with subjectivity.

Summary - *Pinus pinaster* families were found to be stable and highly adaptable to the environment in which they were tested. One breeding population of this species is adequate for afforestation in WA.

RESULTS AND IMPROVEMENT OBTAINED

The Importation Project

Introduction

A major feature of the improvement program was the importation of clones and test material directly from Portugal to supplement the limited breeding base in WA.

Seed of 65 of the 85 plus trees selected in Portugal (Appendix I) was imported directly for half-sib progeny testing. The first half-sib trials planted, XS01 to XS06, contained five families and were linked by one common family. Later tests compared the performance of the open-pollinated families with a routine control batch in trials XS07, XS08 and XS09 (Table 19) and through the standard family in trials XS05, XS09, XS13, XS14 and XS15. Many other families were common to both sets of tests and, with trial XS09, served to link comparisons with both the standard families and the commercial control.

TABLE 34

Height growth (m) of *P. pinaster* families growing at four sites in Western Australia and two sites in Victoria. Measurements are at age 3.5 years in WA and 4.5 years age in Victoria.

FAMILY	MANJIMUP		YANCHEP		HAMEL		GLENCOE		MOWAT		GNANGARA		MEAN	
	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht
E50xE33	3	3.65	2	3.45	1	3.55	2	3.47	9	2.03	2	1.90	1	3.01
E50xE40	1	4.03	4	3.35	7	3.05	1	3.51	1	2.26	5	1.77	2	3.00
E46xE40	2	3.72	6	3.27	2	3.44	3	3.43	4	2.14	8	1.73	3	2.95
E53xE41	5	3.49	9	3.04	4	3.28	4	3.20	6	2.13	1	1.92	4	2.84
E46xE33	4	3.56	1	3.55	8	2.98	5	3.10	8	2.04	6	1.74	5	2.83
E46xE41	7	3.24	3	3.41	3	3.30	6	2.97	7	2.10	3	1.86	6	2.81
E46xE14	9	3.09	7	3.18	6	3.15	8	2.87	2	2.18	4	1.79	7	2.71
E53xE14	6	3.40	5	3.33	9	2.69	7	2.90	3	2.17	7	1.74	8	2.70
E49xE33	8	3.14	8	3.16	5	3.24	9	2.77	5	2.14	9	1.54	9	2.66
Mean		3.48		3.30		3.18		3.14		2.13		1.78		2.84
LSD(0.05)		0.37		0.23		0.51		0.44		0.34		0.31		0.15
Routine		2.87		2.93		-		2.54		1.66		1.60		

TABLE 35

Height growth (m), of *Pinus pinaster* families growing in Victoria, South Africa and two sites in Western Australia.

FAMILY	SOUTH AFRICA		VICTORIA RENNICK		WESTERN AUSTRALIA GNANGARA		WESTERN AUSTRALIA YANCHEP		MEAN	
	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht
E46xE154	1	5.94	4	1.74	1	3.81	2	3.56	1	3.59
E19xE182	3	5.48	1	2.27	3	3.65	3	3.36	2	3.55
E53xE154	5	5.24	3	2.14	5	3.58	1	3.68	3	3.54
E53xE182	4	5.32	2	2.17	4	3.60	5	3.22	4	3.44
E46xE182	2	5.70	6	1.61	2	3.60	4	3.35	5	3.42
Routine	6	5.20	5	1.74	6	3.55	6	3.19	6	3.28
Mean		5.48		1.95		3.65		3.39		3.47
LSD p=0.05		0.35		0.30		0.31		0.20		0.14

TABLE 36

Evaluation of imported clones in half-sib tests, relative to the performance of the routine commercial control (good) and the standard family (very good). Values are percentages of the total clones assessed for each character.

Clone class	CHARACTER ASSESSED					
	Height	Diameter	Straight -ness	Branch size	Branch angle	No. forks
Superior to the routine	47	46	88	100	100	89
Equal to or superior to standard	47	33	31	31	42	30
Number evaluated	58	57	52	52	19	47

Results - For the assessed characters of height, diameter, straightness, branch size, branch angle and apical dominance the percentage deviations from the control or standard were ranked in ascending order. The proportion of the total families ranked higher than the values for the routine control and standard family were determined (Table 36) for each character.

Discussion - Plus tree selection concentrated on attributes of stem form and 88 per cent of the imported half-sib progeny were superior in stem straightness and apical dominance to the commercial routine. All the selected trees transmitted superior branch size and branch angle characteristics to their offspring.

Forty-seven per cent of the trees selected for dominance in vigour in Portugal maintained this attribute in WA and produced heights and diameters superior to the commercial routine.

The mean for standard families used to link trials ranked within the top 10 per cent of families progeny tested in WA. Comparison with this standard provided an assessment of the number of clones transmitting desirable qualities.

Approximately 30 per cent of families assessed (Table 36) were of high quality for diameter, straightness, branch size and apical dominance. Forty-two per cent had superior branch angle and 47 per cent had strong early height growth.

The imported clones expressed at a high level the characters considered to be important to the program. Thirty parents (Appendix XII) were suited for second generation selection.

Phenotypic Evaluation

Results of the plus tree classification based on the expression of phenotypic characters as assessed in Portugal (Appendix I) can be related to the evaluation from progeny testing (Appendix XII). After progeny testing, approximately 40 per cent of phenotypes selected in Portugal were classified as above average and 60 per cent as average or below average. This was irrespective of whether they were judged as first, second or third priority parents during the phenotypic selection phase in Portugal (Table 37). There is little point in taking phenotypic classification to extremes as the genotype in plus selections is only assessable through progeny testing. Nonetheless, the high proportion of plus selections suitable for the first generation program (approximately 70 per cent) resulted from the high selection index and standards employed.

Results from well designed half-sib trials were adequate for evaluation in the first generation breeding program, providing good information on general combining ability of the parents. Their use can greatly reduce the time and cost otherwise involved in testing controlled pollinations to guide culling in first generation orchards. The unavailability of half-sib seed lots prevented use of this evaluation procedure for locally selected clones and 20 of the imported clones.

TABLE 37
Relationship between the rating of Portuguese plus trees based on phenotypic expression and the rating available from progeny test data.

PROGENY TEST RATING	PHENOTYPIC RATING		
	FIRST	SECOND	THIRD
Very good	5	8	3
Good	7	3	5
Average	7	5	5
Poor	4	4	4
Very poor	5	8	4
Total trees	28	28	21
Above average (%)	43	39	38
Average (%)	25	18	24
Below average (%)	32	43	38
TOTAL	100	100	100

Evaluation of Parents

Introduction

Only limited progeny test results were available for the first culling of the Joondalup seed orchard. However, it was possible to distinguish from progeny performance that three of the 16 clones used in the orchard were below standard. Two of these, E15 and E28, had visible phenotypic limitations but the third, E02, was the best favoured phenotype at that time. Results in early tests, even with few clones involved, were therefore reasonably conclusive.

The task of parent evaluation in the Mullaloo seed orchard was much more formidable and complex. A greater number of clones employed (92), a wider range of characters expressed in the phenotypes and the desire for an improvement on the Joondalup seed orchard required a more systematic and objective approach to the sorting task.

The Database

The families were ranked in order of merit for the character concerned as each trial was measured and analysed. An average performance level was developed to compare General Combining Ability (GCA) for each parent in each character measured. The deviations of each family from the mean of the standard families in the trial were expressed as a percentage deviation. Percentage deviations from the trials for families with one parent in common were averaged to provide a performance level for the common parent.

The soundness of the performance figure obtained depended on the number of trials in which families containing the parent had been evaluated and the range of other parents represented in the crosses. Each clone was crossed with at least three tester pollens and GCA is expressed at least on this basis. For the imported clones this limited data set for pollen was supplemented by the results for half-sib tests. At any time in the developing program, however, the test data for any one clone was limited to the actual trials measured to that time.

As the testing program developed further information became available for each clone and the evaluation of parents with superior GCA for height, diameter, straightness, branching and crown attributes clarified. The first full evaluation of the test program was not possible until 1987.

The combination of the most acceptable characters in a parent included in the seed orchard was weighted to favour stem straightness and branching quality, with no serious loss of vigour. For the first culling of Mullaloo seed orchard in 1978, data from progeny trials on stem form were limited. Information on attributes of ramets, in both the clone arboretum and the seed orchard, assisted decision making. Adequate data were available from trials for the culling in 1981 and 1985.

All progeny test data have been transferred to a database suitable for desktop computers. Results for mean height, diameter, straightness, branch size, branch angle, apical dominance and their deviation from the mean of the standard families can be obtained for any male or female parent, or family, for each trial or combinations of such.

Combinations of families or parents can be extracted to assess GCA and SCA as required. It is also possible to immediately list those families with acceptable height and diameter deviations which meet set criteria for straightness, branching and apical dominance.

The database is accompanied by a management database containing historical information on location, design, establishment, pruning, thinning, fertilizer application and measurement data for each trial. This is useful in maintaining management requirements for the trial series. All breeding operations and information can be immediately accessed by TBIMS (Butcher 1993).

Insect Resistance

An unexpected benefit from the program was the ability to separate the clones according to their resistance to attack from the pine woolly aphid (*Pineus pini*).

The pine woolly aphid has been known in local plantations since the early 1940s. It is common on scions from mature branches and on the stems and branches of young thin barked trees, particularly in wet sites. It was a minor problem on scions and stocks in the grafting program. The woolly aphid has not been found to have deleterious effects on pine growth under local conditions.

This insect is associated with problems with pines in other parts of the world. Zwolinski *et al.* (1989) have associated the insect with damage to the crop of *P. pinaster* in South Africa. Infestations may be increased by off-site planting resulting in unthrifty stands (Barnes *et al.* 1976; Tanton and Alder 1977).

In local infestations of woolly aphid great variability in the intensity of infestation has been observed to occur between trees. The extent that this variable resistance is associated with genotype was measured in an assessment of the Mullaloo seed orchard.

Procedure - Seventy-eight clones planted in 1969-70 in the Mullaloo seed orchard were randomized within 46 blocks to total 3597 grafts. In July 1978 the presence or absence of the woolly aphids on each graft was noted in conjunction with a BSTAF classification of the ramets.

Results - The percentage of ramets infected for each clone varied from 0 to 100 with the majority of clones showing a high resistance to the insect attack (Fig. 30).

It is obvious that selection against *Pineus pini* could be effective within the breeding population under local conditions. There is no indication that this is warranted but details of the study have been forwarded to South Africa where much of the local breeding population has been introduced.

Heritability and Genetic Correlations

Introduction

The basis of the tree breeding program is the transmission of characters from parent to progeny. However, at the commencement of the program in 1957 and in its early management there were no data for heritability of the species. The first generation program was therefore guided by general suppositions about the inheritance of different traits.

Heritability estimates based on results from progeny testing are now available to assess the performance of the first generation parents and serve as essential ingredients in any second generation program.

Heritability

All relevant trial data were processed with a 'least squares' analytic program (Harvey 1988) to determine heritability and genetic correlations. Results are averaged for ten of the random pair mating trials in Table 38 and provide the genetic library for the species in Western Australia.

Estimates of heritability vary with trial type, family compliment and age. Values for height, diameter and branch angle obtained are generally moderate to high. Excellent improvement in vigour can be expected for the species.

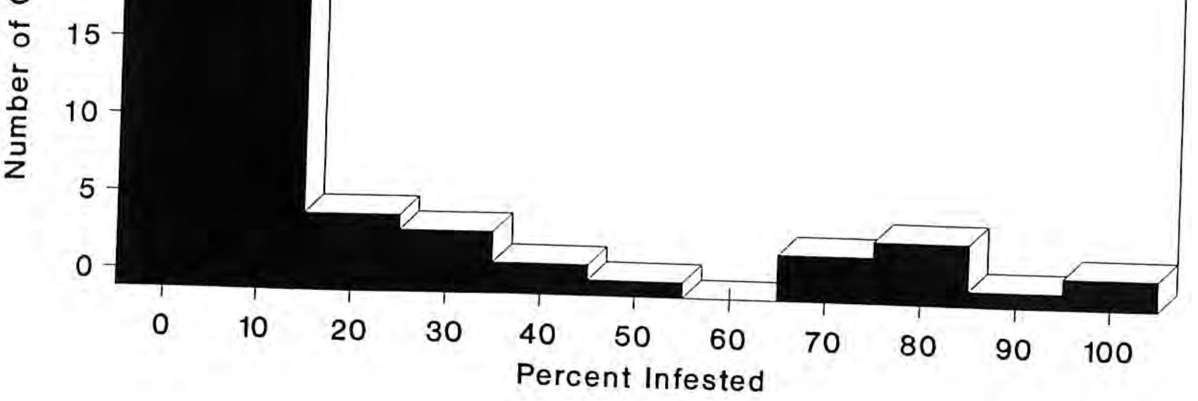

*Figure 30. Distribution of the degree of infestation by the pine woolly aphid (*Pineus pini*) within clones in the Mullaloo seed orchard.*

TABLE 38

Average genetic parameters for production traits of *Pinus pinaster* from 10 random pair mating trials in Western Australia. Genetic correlations are presented above the diagonal and phenotypic correlations below the diagonal.

TRAIT	HERIT-ABILITY	CORRELATIONS				
		BASAL AREA	HEIGHT	STRAIGHT -NESS	BRANCH SIZE	BRANCH ANGLE
Basal area	0.24	-	0.66	-0.26	-0.28	0.02
Height	0.28	0.73	-	-0.21	0.01	0.16
Straightness	0.14	-0.14	-0.15	-	0.26	-0.04
Branch size	0.12	-0.30	-0.22	0.20	-	0.15
Branch angle	0.22	0.09	0.11	-0.03	0.10	-

Heritability for bole straightness and branch thickness were surprisingly but consistently low and do not indicate the large gains achieved from mass selection in the first generation. Heritability estimates should be based on populations where there has been no selection for the trait concerned (Cockerham 1963). Selection locally has been intensive for traits associated with tree quality. The plus phenotype has consistently ranked above the routine plantation seed source and while there was always a large difference in appearance between these trees and the pedigree trees, the pedigree trees were remarkable for their uniformity. This probably accounts for the low heritability estimate.

Heritability values obtained for stem straightness are of the order of 0.14. This character was a main focus of selection and it is likely that significant improvement can only be achieved through very intensive selection procedures and family selection (Falconer 1981). This realization should more than justify the cost and effort made to obtain a suitable number of straight trees through selection in Portuguese stands.

Values for branch thickness are also low to moderate (0.12). Heritability for apical dominance is low, indicative of slight improvement in this character. It too was favoured in the selection of plus trees.

Genetic Correlations

Correlations between the assessed characters calculated by least square procedures are summarized in Table 38. As with heritability there was considerable variation between trials but some obvious patterns emerged. Height and diameter were strongly correlated and selection to favour either can be expected to favour improved volume.

Both height and diameter were negatively and weakly correlated with stem straightness and branch thickness.

Straight stems were positively correlated with small branches while there was no correlation with branch angle. Results for straightness and apical dominance were reasonably high (0.5-0.6) and positively correlated suggesting that improved straightness is associated with improved apical dominance.

Discussion

Data obtained for heritability result from the first generation program and were seen as a major requirement of that stage of the improvement process. The library of genetic data was compiled principally to allow index selection (Cotterill and Dean 1989) for the second stage program. It is being extended as further results are obtained from the later trials.

Cotterill *et al.* (1987) have produced data on heritability for *P. pinaster* in South Africa which provide some basis for comparison to age eight years. For height and diameter individual heritability were 0.19 and 0.04, compared with an average of 0.28 and 0.22 assessed from WA trials of similar age (Table 38). Heritability for stem straightness was assessed at 0.03 compared with local average of 0.14.

Cotterill *et al.* (1987) state that the straightness value is erroneously low as a result of the way the 8-point subjective scoring system was used. Low values obtained for heritability of straightness in the local program have also been attributed to inadequate BSTAF assessment. It has been suggested, however, that the low local value was also dependent on the very high selection standards on straightness for all parents used to evaluate heritability in the full-sib program.

The genetic correlations between height and diameter were found to be very strong (0.88) in the South African trial, as was the case in WA.

TABLE 39

Average deviation (Dev) of full-sib families in progeny tests from a routine seed source

ATTRIBUTE ASSESSED	PROPORTION OF FAMILIES						
	TOTAL			TOP 25%		TOP 10%	
	No.	Dev (%)	Routine average	No.	Dev (%)	No. (%)	Dev
Height (age 4.5years)	1248	10	-	312	23	125	28
Diameter (age 7.5years)	997	10	-	250	21	100	24
Good straightness[a]	691	44	53	174	108	69	141
Excellent straightness[b]	697	171	8	171	450	70	673
Good branch size [a]	691	28	59	174	73	69	107
Excellent branch size[b]	490	133	5	122	457	49	728
Good branch angle [a]	601	23	23	151	127	61	191
Good apical dominance	625	4	51	157	45	64	69
Absence of stem forks	408	24	36	103	159	41	252

[a] Percentage of stems of class 1, 2, 3 - Acceptable crop

[b] Percentage of stems of class 1, 2 - Plus stems

Improvement Obtained

Introduction

Two procedures were used within the program to gauge the progress and assess the degree of improvement obtained. One was based on the standard progeny test procedure, the other established separate yield trials designed to measure progress under simulated commercial conditions.

The Routine Control

The commercial routine seed source incorporated in 48 trials was measured and assessed as a normal breeding family. The mean of the routine family was subtracted from each family mean to list the deviation from the routine. Deviations, expressed as a percentage of the routine mean to allow comparisons between trials, are summarized in Table 39. Average and maximum deviations for each trial, are listed in Table 40.

The number of families averaged varied with the attribute measured (Table 39). Comparison was made for 45 trials for height, 28 for diameter and 21, 22, 7 and 17 trials for straightness, branch size, branch angle and apical dominance, respectively. The values in the 'Numbers' column in Table 39 refer to the family means compared in each trial. Each family mean was based on a minimum of 20 trees but usually represented in excess of 50 measured trees.

Results in Table 39 were a useful guide to progress and the potential for gain within the program. They also provided an insight into what future populations may be like. Butcher (1977a) published an early indication of this progress from data available up to 1976.

Tree Form - On commencing the selection program stem straightness was regarded as the major commercial defect of the provenance. Average improvement of good straight stems of final crop standard was 44 per cent and for excellent stems (plus tree quality) 171 per cent. These values compare favourably with earlier assessments of 42 and 150 per cent respectively made by Butcher (1977a) with fewer families and trials. From the average value for the routine (Table 39) it can be calculated that an improved population would contain 73 per cent of trees of acceptable crop straightness and 22 per cent of trees of plus tree standard for straightness. With knowledge of these estimates it was possible to reduce plantation spacing, once seed orchard seed became available in 1972. This led to large savings in existing nursery, planting and early pruning and culling costs with no detriment to the final crop.

Branch Size - Full-sib families in trials assessed (Table 39) gave 28 per cent more trees with branch size of acceptable crop standard and 133 per cent more of plus tree standard. This relates to a population with 74 and 12 per cent of good and excellently branched stems respectively.

Butcher's earlier estimate was for 68 and 100 per cent improvement, respectively, over the routine to give a population of 74 and 8 per cent of good and excellent trees. Population estimates agree but the routine and deviation from the routine vary. This is to be expected from the variation in branching data for the routine seed source which has been shown previously in data in Table 22.

Table 40

Average and maximum deviations from the Routine value for Leirian families in trials which included the control. Values are expressed as a percentage of the Routine.

Trial No.	No. Observations	Height		Diameter		Straightness		Branch Size	
		Average	Max.	Average	Max.	Average	Max.	Average	Max.
YS01	6	21	25	25	30	3	9	13	21
YS08	19	6	10	2	9	*	*	*	*
YS09	19	4	10	7	14	*	*	*	*
YS10	19	3	9	5	11	8	11	30	42
YS11A	29	16	26	15	21	12	20	6	16
YS11B	29	20	37	12	27	*	*	*	*
YS12	20	3	21	4	17	*	*	*	*
YS13A	29	13	23	11	17	8	19	15	29
YS15	9	13	25	6	10	35	50	17	24
YS16	15	-1	18	1	9	19	33	17	25
YS18	31	20	46	10	25	10	20	6	15
YS19	31	12	20	8	13	13	22	10	19
YS20	31	16	45	16	29	16	29	11	17
YS21	31	15	25	16	27	*	*	*	*
YS22	26	4	27	14	19	36	51	20	31
YS23	31	18	35	11	27	*	*	*	*
YS24	31	17	34	20	31	*	*	*	*
YS28	33	2	14	3	15	17	27	7	16
YS29	33	7	15	14	20	13	31	-2	2
YS30	33	6	16	14	22	*	*	*	*
YS31	33	21	32	21	33	*	*	*	*
YS32	29	9	20	7	23	2	11	3	13
YS36	14	21	33	21	31	*	*	*	*
YS37	24	5	16	7	23	*	*	*	*
YS38	16	7	21	7	18	*	*	*	*
YS40	32	1	20	3	20	19	31	12	26
YS41	32	8	32	7	19	7	19	9	22
YS44	29	11	26	7	20	26	39	5	17
YS45	46	-1	25	4	16	15	22	19	34
YS46	46	4	21	7	17	17	26	7	20
YS47	46	10	22	17	24	-1	13	5	15
YS48	23	5	17	8	14	8	16	17	26
YS49	82	15	35	13	28	9	26	4	16
YS50	79	13	39	11	24	19	32	12	25
YS51	28	2	13	8	13	13	23	3	20
YS52	27	5	18	13	17	6	13	3	6
YS53	27	9	29	11	17	16	29	6	20
YS54	87	11	30	8	24	12	32	6	28
YS56	62	16	43	10	28	16	34	-1	14
YS66	35	4	19	8	17	60	108	36	64
Average		10%	25%	10%	20%	15%	28%	11%	22%

* Data not available.

Branch Angle - Relatively few comparisons were available for branch angle but from the tests of variability carried out (Table 22) it is believed the results can be viewed confidently. Results indicate improvement over the routine to be 23 per cent, providing a population with 28 per cent of trees of acceptable branch angle. Provenance studies (Hopkins and Butcher 1993) have shown that there is little variation in the high branch angle that is characteristic of the Leirian provenance and that ideal, flat branching is not a characteristic of the species. Branch angle improvement, as assessed, eliminates the trees with excessively steep branching. Data for the top quartile and percentile in Table 39 indicates that there is considerable opportunity for further improvement.

Apical Dominance - Provenance trials have shown that stem forks and ramicorns are an undesirable feature of the Leirian provenance (Hopkins and Butcher 1993). Results in Table 39 show a 4 per cent improvement over the routine for good straight trees without ramicorns and forks and a 24 per cent reduction in forking. Selection within the top quartile of families for the character may provide a population with up to 73 per cent of trees with favourable apical dominance and absence of forks. Heritability calculated for apical dominance were few and low but a high genetic correlation for straightness and apical dominance suggests that apical dominance will improve as a result of the intense selection for straightness.

Tree Vigour - The average improvement in progeny trees on the height of routine trees is 10 per cent and that for the best quartile is 23 per cent. This compares favourably with the earlier estimate of 15 per cent by Butcher.

Average diameter improvement at age 8 years is 10 per cent while that of the top quartile is 21 per cent. Butcher did not provide values for diameter but suggested that volume increases could be from 20 to 90 per cent above the unimproved seed source. Volumes were not calculated for many of the progeny trials but sawlog volumes are considered in the yield trial. Since volume is a function of the product of height and the square of diameter, it is expected from indications in Table 39 that the commercial realization of gross volume could be that indicated by Butcher's earlier estimates (Butcher 1977a).

Summary - The incorporation of the routine source into the progeny test program as a bench mark provided useful indications of progress and potential of the program in its early days. The field demonstrations of the superior performance of select families, alongside routine planting stock, were of general interest and favourable to the continuation of the breeding work.

Average deviations from routine performance in Table 39 include all families from parents which could have benefit to the program. The early trials were with tester pollens and several of these parents have been discarded owing to poor performance. Inclusion of data from these trees adversely weights the average in Table 39. Improvements indicated from the top quartile or percentile are probably a more appropriate gauge of the potential for seed from the heavily culled Mullaloo orchard.

As orchard seed became available it was incorporated into progeny trials to indicate its worth. Results in Table 41 (for eight trials) relate to the first yields of seed from the unculled Joondalup seed orchard. Comparisons in the table relate the population measured from the orchard seed with the associated routine population and, in the final row, the average improved population estimated from the progeny trials (Table 39). These comparisons indicate that the promise for the average improvement, shown by the trials, was achieved for all attributes.

Yield Trials

Estimates of production gains based on controlled crosses tend to be inflated as they avoid the limitations of open pollinated matings in seed orchards, for example, selfing, related mating, temporal variation in flowering and preferential mating. Realistic estimates of gain need to be based on operational seed orchard collections compared with the seed source previously used.

Yield trials were planted in 1973 at Gnangara on Bassendean dune grey sands and at Yanchep on a Spearwood yellow sand sample site typical of the major pine afforestation area on the Swan Coastal Plain. Trials included seed collected from the Joondalup seed orchard, seed from a managed seed production stand, seed from a local plantation, and seed imported from the Forest of Leiria in Portugal.

The Gnangara trial had four replicates of two spacing treatments (2000 and 1140 stems ha^{-1}) for each of the four seed sources. There were five replicates in the Yanchep trial. Plot size was 0.06 ha and contained either 120 or 70 trees.

Results from the Gnangara trial at age 11 years have shown that improvement in the seed orchard product was highly significant for both gross volume and factors which influence the useable volume such as butt sweep, general stem straightness and reduced branch size. The seed production stand, an interim stage in the improvement process, was also significantly better than the control for volume of the whole stand and for height, diameter and volume of the final crop selection (Butcher and Hopkins 1993).

Overall Gain - The genetic gains achieved (Fig. 31) were summarized by Butcher and Hopkins (1993) as:

1. increased volume production (+ 36 per cent);
2. better quality timber produced and higher recovery because logs were straighter (+ 31 per cent) with smaller limbs (+ 7 per cent);
3. improved selection potential for the 250 final crop trees per hectare; and
4. less variability in the plantation, improving the management efficiency and harvest.

TABLE 41

Percentage deviation of early orchard seed lots from measurements of the commercial routine. Actual population values for the average routine and orchard population are included and compared with the improved population estimated from trials.

	HEIGHT	DIAM.	STRAIGHTNESS Good	STRAIGHTNESS Very good	BRANCH SIZE Good	BRANCH SIZE Very good	BRANCH ANGLE Good	APICAL DOMIN. Good
No. of trials	8	5	5	3	5	2	2	5
Percentage deviation	11	3	4	63	11	-12	72	22
				Percentage in the population				
Orchard population	-	-	67	21	70	41	32	49
Routine population	-	-	52	17	64	11	18	44
Population estimate from trials	-	-	73	22	74	12	28	53

Height and diameter gains of 11 and 8 per cent respectively, were about the same as the average gain of 10 per cent estimated for all full-sib seed over the routine control from progeny trials (Table 39).

The improved seed came from the early Joondalup orchard in which the parent clones were limited in numbers and quality. Six of the clones were later removed on the basis of unsatisfactory performance in early progeny trials.

Further yield trials were planted in 1989 to evaluate the orchard output. These incorporated seed from both the unculled and culled Mullaloo orchard as well as the local routine, Joondalup orchard and seed stand sources used in the current trial. Trials were planted at Gnangara and at Myalup plantation at Harvey. The seed sources were also sent to Portugal for yield testing in the native environment.

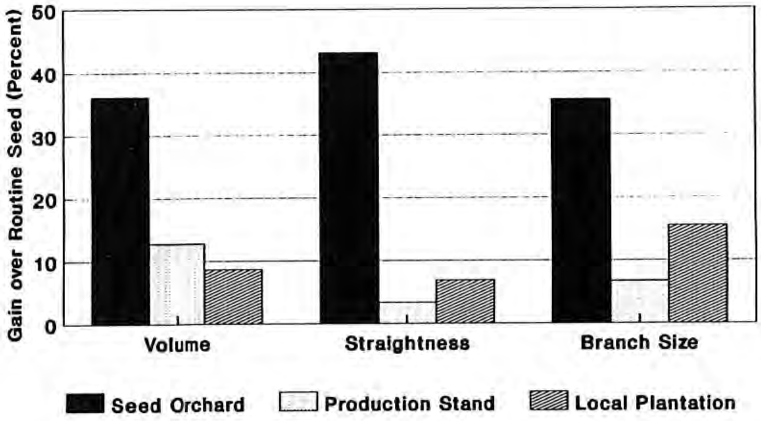

Figure 31. Gains obtained in the Gnangara yield trial at age 11 years. Gains are expressed as the percentage increase over the routine seed source.

THE BREEDING PLAN

Introduction

Culling the Mullaloo seed orchard from progeny test information in 1985 (Fig. 32) completed the first generation breeding program. The resulting seed yield will meet local requirements for the immediate future. The improvement obtained exceeded the expectations for the program when it began in 1957. A second generation orchard has been established at Manjimup.

The Second Stage Program

In 1973 several of the best individuals from the best families measured in progeny trials were controll-pollinated with pollen from outstanding clones. This action, together with the extensive random pair mating project begun in 1972, initiated the second generation breeding stage.

The second generation program concerning the selection of new genetic combinations has now developed to the stage where a clone arboretum and seed orchard have been established.

The Genetic Resource

A total of 152 plus trees were considered in the first stage of the program (Appendix II). These were selected by intensive searching of the native Leirian stands in Portugal, from the best local plantations and from plantations in South Australia and South Africa. No recent attempt has been made to select additional trees from the increasing areas of maturing plantation. Focus has centred on the new families developed from controlled pollinations.

Parents for the second generation of the program have been designated as follows:

1. E. Series - this comprises 30 of the first generation clones shown to have outstanding properties for transmission of favourable traits;
2. K Series - this contains 123 clones selected from the best ortet open-pollinated families imported from Portugal. For each selected family, a minimum of two trees with the best breeding potential were chosen;
3. S Series - this third series contains 200 clones from the best individuals of the best unrelated families in the progeny tests, including both the tester and the random pair mating series. Two individuals were again selected for each of these superior families.

Most of these 353 second generation selections have been cloned by grafting and ramets have been planted in the Hopkins Road clone bank at Pinjar and the best of them in the seed orchard at Manjimup. These were planted over the period 1985 to 1989.

Selection Criteria - Identification of second generation parents for the breeding population was mostly on the basis of the best tree in the best families in trials. The first selections were made by identifying those trees in the better families with superior stem and crown form characters. These were compared on the basis of their vigour which was adjusted to allow for block differences. These were identified from the measurement record and then checked in the field to confirm their suitability. Candidate plus trees for the second generation were analysed for wood properties as a final criteria for selection. Trees with a juvenile wood density equal to or better than the mean of 430 g cm^{-3}, obtained for all pedigree trees, were considered as acceptable final selections.

Index Selection - The availability of genetic information from progeny trial data in the mid to late 1980s opened the way for index selection as a mainstay to the second generation program. Index selection (Cotterill and Dean 1989) generally has been shown by theoretical studies and field trials to be the most practical and efficient method of selection available to breeders. The main appeal of index selection compared with the commonly used independent culling, is that it allows for excellence in one trait to compensate for weakness in the other. Index selection makes better use of relatives (family selection) and does not concentrate on the phenotypic value.

With the library of genetic parameters now available for each trial (Table 38), breeding values for the early selections have been checked by multiple trait, combined family and individual index selection. Trees of outstanding breeding values, identified by index selection and confirmed in the field, that are not already included in the breeding population are being grafted and added to the clone bank.

The Second Generation Clone Bank at Pinjar

The major second clonal archive is located on Hopkins Road in the Pinjar group of plantations. An area of 8 ha is available for cloning of the breeding population parents. Some *P. radiata* selections have also been planted at this site.

Unit 1 was planted with clones from the New Zealand *P. radiata* 268 series in 1983. Unit 2, of area 0.5 ha, of the clone bank was planted in 1985 with 200 grafts of the first 69 second generation selections, and in 1986 with 140 rooted cuttings from the best 32 controlled pollinated families in the *P. pinaster* program.

Unit 3 has an area of 3 ha and was planted in 1988 with 2250 grafted ramets, comprising 30 clones from the E series, 72 from the K series and 52 from the S series of the breeding population.

Unit 4 has an area of 3 ha and was partly planted in 1989 with grafted ramets derived from 41 additional clones in the S series. This was added to in 1992 with ramets of new selections that have been identified as outstanding breeding trees from index selection.

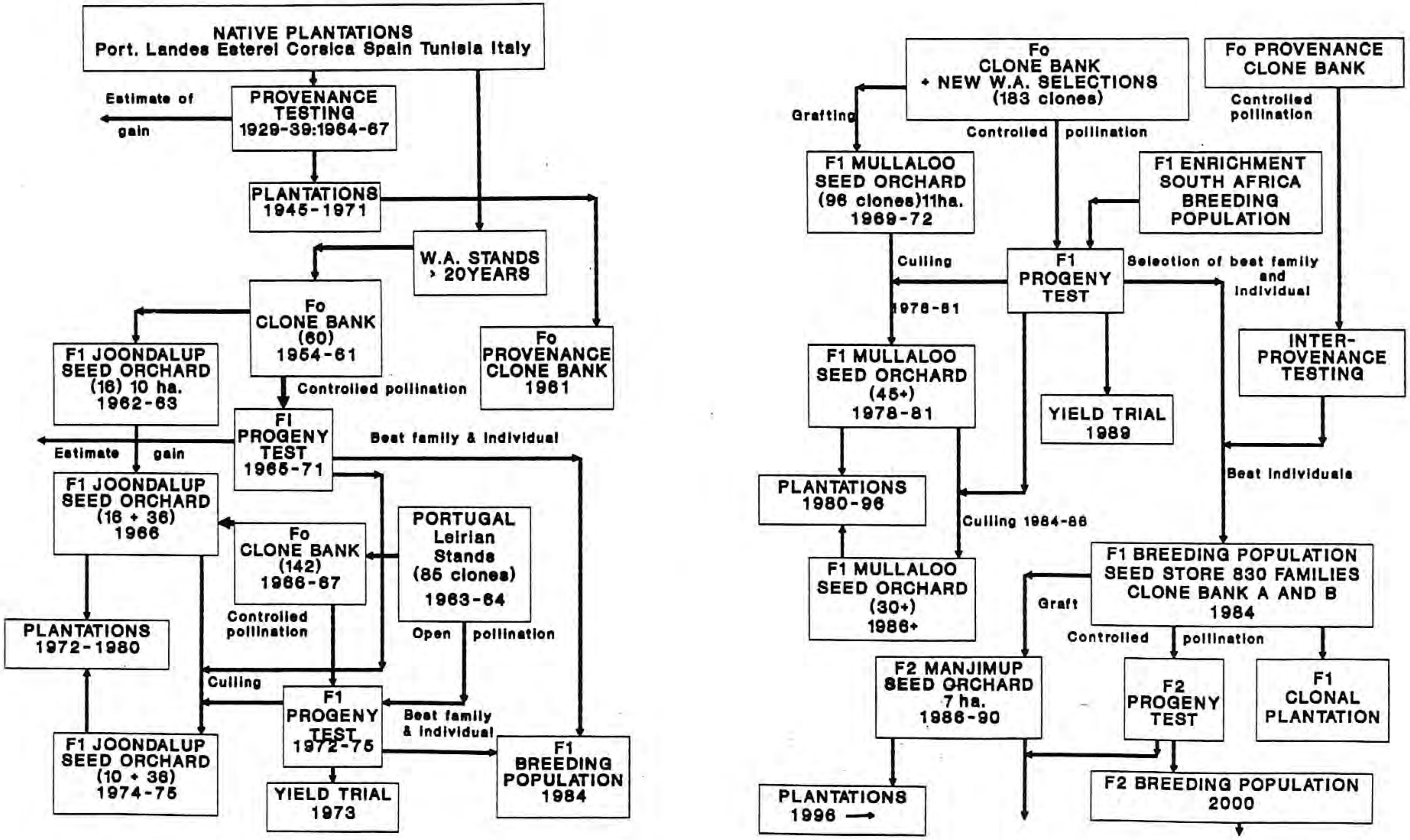

Figure 32. The breeding plan for the P. pinaster *improvement program, presented in two parts for convenience. The first generation plan culminates in the culled Mullaloo seed orchard. The Manjimup orchard is the initial production stage of a second generation plan.*

The Manjimup Orchard

The orchard at Manjimup is located at the Department's Plant Propagation Centre and was planted over the period 1986 to 1990. It is 7 ha in extent, with ramets spaced at 8 m x 6 m. The orchard has a conventional randomized block design of clones to maximize outcrossing through open pollination. Particular care was taken in the positioning of clones to avoid common ancestry in adjacent ramets.

The orchard contains grafts of 222 clones; 30 are the best from the E series, 60 from the K series and 132 are from the S series. The number of ramets per clone is variable with many more ramets per clone for the better ranked clones. This is an unusually large clonal composition for a production seed orchard. With the future role of the species in WA uncertain, a strategy to use a large number of selections has been adopted.

All clones in the orchard have parents with defined progeny performance and 152 result from recombinations selected in progeny test stands. The orchard contains new parent material to incorporate families from pollens of nine excellent trees obtained from South Africa. All clones used in the orchard have been screened to provide desirable wood density in progeny.

Manjimup is a site better located for future plantation management and should be subject to less damage from birds. Observations also indicate that higher rainfall and cooler temperatures should provide maximum seed yields for the species.

Useful seed yields should become available from 1995. Artificial pollination could be practised on the orchard in the early years.

Potential Genetic Gains

Results to date show that a realized gain in wood volume of more than 36 per cent, from our first generation seed orchards, is accompanied by extensive gains in tree quality traits such as bole straightness and branch size (Tables 39, 40, 41, 42). The potential for genetic gains from the second generation orchard at Manjimup is equally as promising. Information on genetic parameters (Table 38) is reliably based and gives some confidence for the predictions. The genetic gain in sectional area growth is calculated to be about 16 per cent as consequence of family and within family selection and selection differentials of 1 : 100 (Table 42). Because vigour is negatively correlated with form traits of *P. pinaster* (Table 38), it is not possible to achieve substantial gains in bole straightness and branch quality while seeking improvement in growth rate.

Outstanding response to selection for form traits was achieved in the first generation. Maintenance of this degree of improvement will satisfy seed requirements for the dry coastal plain plantations. Calculations in Table 42 show that bole straightness will not be further improved and that branch thickness will only be improved by about 6 per cent. Though small the gains realized will be useful.

The objective of the second generation program is to optimize growth rate while maintaining above average wood density and the improved bole straightness and crown quality obtained from the initial breeding stage. This strategy recognizes that additional improvement in form traits would be at the expense of increased growth rates.

The Breeding Plan

The breeding plan for the species in WA, summarized in Figure 32, was conceived in an economic climate which envisioned up to 80 000 ha of *Pinus pinaster* plantation providing a major wood source for development in the State and a sound use for otherwise unproductive land. This led to the first stage program (Fig. 32) which has produced all seed required since 1971.

In the 1980s Government policy banned the further clearing of native woodlands for plantation establishment. There was also considerable community concern on the water use of pine trees on the aquifer of the Gnangara Mound. Changing land use objectives to optimize both water and timber production required wood production be below the potential for the site. On these terms the species is economic only on the better quality sites and plantation extension has virtually ceased.

During this time, the Department's tree breeding team has switched priorities to the rapid improvement of *P. radiata* for growth and form, and for resistance to *Phytophthora cinnamomi* (Butcher *et al.* 1984). The tree breeding station and staff at Wanneroo were relocated to Manjimup, in early 1990, to better serve this new priority and plantation development area.

This review has documented the successful completion of the first generation of the plan. The strategy for advanced generation breeding must now be considered.

Continued Improvement of P. pinaster *in Western Australia.*

Objectives of the breeding plan are to most efficiently use the available genetic, human and physical resources to maximize gain per unit of time, without prejudicing longer term breeding, and to transfer realized gains to the production plantations.

There are two main aspects to any successful tree improvement program:

1. An operational or production phase directed to produce economic gains as rapidly and efficiently as possible. This has been achieved for the local program (Table 18). Forty-two per cent of the State's *P. pinaster* forest is of seed orchard origin which may produce 36 per cent more wood volume on trees with significantly improved stem and branching quality (Tables 39, 40, 41, 42, Fig 31).

TABLE 42

Realized gains (%) from the first generation program and potential future genetic gains from the breeding of *Pinus pinaster.*

TRIAL	REALIZED GAIN[a]			POTENTIAL FUTURE GAIN[b]		
	BASAL AREA	STRAIGHT-NESS	BRANCH SIZE	BASAL AREA	STRAIGHT-NESS	BRANCH SIZE
			Pollen tester trials			
YS28	6	17	7	12	0	1
YS29	28	13	-2	2	4	1
YS45	10	15	19	15	2	2
YS46	16	17	7	7	3	3
YS47	36	-1	5	5	5	8
YS48	18	8	17	14	9	9
YS49	28	9	4	16	-3	15
YS50	22	19	12	12	2	3
Mean	21	12	9	10	3	5
			Random pair matings			
YS54	-	-	-	13	8	10
YS55	-	-	-	31	0	6
YS57	-	-	-	25	1	2
YS59	-	-	-	23	0	8
YS60	-	-	-	24	0	8
YS61	-	-	-	20	3	2
Mean	-	-	-	23	2	6
Average	21	13	9	16	2	6

[a] Realized gain computed as the difference between the average pedigree performance and the routine control seed lot.

[b] Potential additional future gain calculated using genetic parameters computed for each trial and selection of the next generation breeding trees at an intensity of 1:100.

A 2.5 to 4.0 per cent volume gain generally is sufficient to justify a tree improvement program (Carlisle and Teich 1970). Malajczuk[1] (personal communication) has calculated that the internal rate of return for *P. pinaster* plantations of improved stock, in the Wanneroo region, will exceed 5 per cent and prove to be economical.

2. A development or research phase relating to the longer term breeding population with the main objective of maintaining a reasonably broad genetic base.

No program can be better than the base of genetic material on which it is founded and the flexibility of the future will be determined by the quality of the breeding population that is established early. The commitment by the Forests Department in 1957 to provide considerable human and physical resources (Perry and Hopkins 1967) has provided an excellent base for the future development of the species in WA. The challenge for the future is to maintain a balance between continuous genetic improvement and the conservation of diversity in the breeding population.

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[1] Dr G. Malajczuk, 1991. Department of Conservation and Land Management, Como, Western Australia.

It is expected that the breeding population for the program will be increased to about 400 parents. This group contains all of the desirable genes for timber production as well as the others that are not being selectively bred at this time. Genetic diversity is maintained in this robust breeding base. With careful planning and implementation of breeding and seed orchard populations genetic improvement in yield and quality and any other trait can be accumulated in each successive generation. This can be achieved without reducing the genetic diversity or reducing potential gains through increased related matings.

Breeding strategies based on present day information and constrained by current economic resources must look ahead for several generations. Advances in technology, biotechnology and genetic engineering will also require amendment of any proposed strategy. Thus, a flexible strategy is essential to allow for change.

The Future

Within the present economic situation and reduced planting of the species the improvement program has been placed on a maintenance basis. The second stage program (Fig. 32) is being developed within a restricted budget. Seed available from the heavily-culled Mullaloo orchard is expected to approach the yield and quality required for current management. A surplus is available for export. This seed and the seed that will be available from the second generation orchard at Manjimup after 1995 should meet the needs of the State.

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APPENDIX I

Classification of Portuguese plus phenotypes on the basis of phenotypic expression.

TREES TO BE GIVEN FIRST PRIORITY	TREES TO BE GIVEN SECOND PRIORITY	TREES TO BE GIVEN THIRD PRIORITY
102	103	101
105	104	106
107	112	108
109	115	111
110[a]	118	113
117	119	114
122	120[a]	116[b]
124	123	121
128	130[b]	125[a]
131	137	126
132	141	127
133[b]	142[b]	129
135	143	134[b]
139	146	136
144	149	138
147	151[b]	140[b]
148	152	145
150	153[a]	163[b]
155[b]	154	167[b]
156	158	172
157	159[b]	173
162	160	176
164	161	177
166[b]	165	TOTAL=23
168	174	
169[b]	178	
170[b]	180	
171	182	
175[b]	TOTAL=28	
179[b]		
181		
183		
185[b]		
186[b]		
TOTAL=34		

---

[a] No live grafts of these clones established in Australia

[b] Seed not available for half-sib testing

APPENDIX II

Parents in the Western Australian Leirian breeding population.

WESTERN AUSTRALIA		PORTUGAL			SOUTH AFRICA
E02[a]	E40[a]	E102	E135	E166	A12
E05[a]	E41[a]	E103	E137	E167	A19[a]
E08	E45[a]	E104	E138	E168	A25
E09	E46	E105	E139	E169	A27
E11	E47[a]	E106	E140	E170	A31
E12[a]	E48	E107	E141	E171	A33
E13[a]	E49	E108	E142	E172	A43
E14[a]	E50	E109	E143	E173	A46
E15[a]	E52	E111	E144	E174	A51
E16[a]	E53	E112	E145	E175	A59
E17	E54	E113	E146	E176	A63
E18	E55	E114	E147	E177	A68
E19[a]	E56	E115	E148	E178	A69
E21[a]	E57	E117	E149	E179	A71
E22	E58	E118	E150	E180	A73
E24	E59	E119	E151	E181	A75
E25	E69	E121	E152	E182	A76
E27[a]	E71	E122	E154	E183	A77
E28[a]	E74	E123	E156	E184	A90
E29[a]	E75	E124	E157	E185	A91
E31	E77	E127	E158	E186	A102
E32	E81	E128	E159		
E33[a]	E84	E129	E160		SOUTH AUSTRALIA
E34[a]	E86	E130	E161		
E35[a]		E131	E162		P02
E37[a]		E132	E163		P85
E38		E133	E164		P86
E39		E134	E165		

[a] Selfed clones

APPENDIX III

Summary of the importation and grafting program.

DATE RECEIVED	PHENOTYPES REPRESENTED	STORAGE METHOD	GRAFT TYPE AND NUMBER			
			TIP	BOTTLE	SIDE	TOTAL
9.9.64	117,123,129,130,132, 133, 139,140,141,142, 143,144,145 146,147, 148,149,150,151	Wet in moss	411	186	-	157
15.9.64	101,102,103,104,112, 113,114,115,116,118, 119,120,121,122 124, 125,126,127,128	Wet in moss	295	172	-	467
22.9.64	105,106,107,108,109, 110,111,115,123,131, 133,134,135,136,137, 138,139,142,152,153	Wet no moss	268	197	-	465
	Total for Season		974	555	0	1529
11.3.65	113,129,146,149,150, 151,155,156,157,164, 165,166,167,184	Dry	162	141	9	312
18.3.65	132,140,143,155,157, 168,171,172,173,174, 175,176,178,180,181,184	Dry	163	159	16	338
25.3.65	103,153,154,155,157, 158,159,160,162,163, 183,184	Dry	126	115	1	242
1.4.65	104,109,110,117,125, 128,136,155,157,161, 169,170,177,179,182,184	Dry	199	148	2	349
	Total for Season	-	650	563	28	1241
23.5.65	105,118,119,152,153,161, 162,163,177	-	211	-	-	211
	Total for Season	-	211	0	0	211
8.9.65	101,128,179,181,182, 185,186	-	135	-	-	135
8.9.65	Grafted in Portugal	-	-	-	-	169
	Total for Season	-	135	-	-	135
Total grafted locally		-	1970	1118	28	311

APPENDIX IV

Survival classes for introduced phenotypes
as at January 1967.

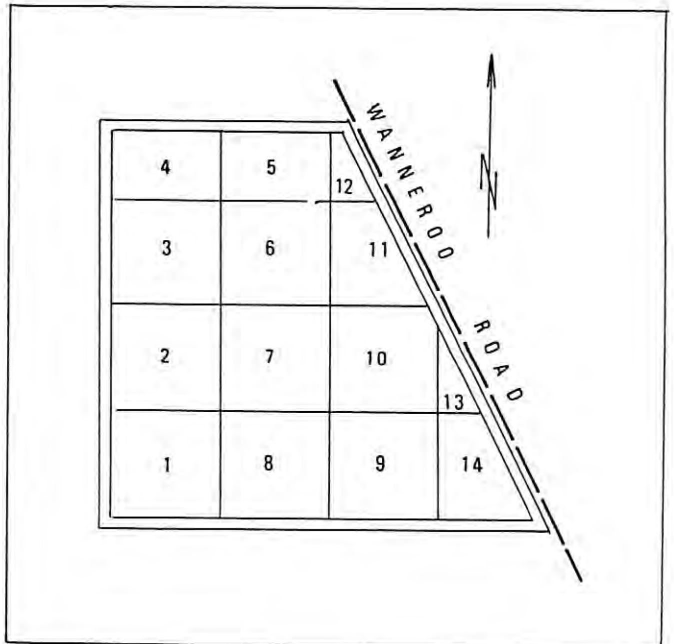
NO. OF SURVIVALS	PHENOTYPES REPRESENTED IN CLASS	NO. OF CLONES
0	E110,116,120,125,136,153	6
1	E101,102,155	3
2	E121,126,140,141	4
3	E103,106,108,109.128,142	6
4	E104,132,135,150	4
5	E137,138	2
6	E115,163,179	3
7	E112,E114	2
8	E124	1
9	E105,113,131,147,181	5
10	E107,111,130,144,170	5
11	E117	1
12	E127,139,177,182	4
13	E165	1
14	E143,172	2
15	E154,161,173,183	4
15+	E118,119,122,123,129,133,134,145,146,148,149,151152,156,157,158,159,160,162,164,166167,168,169,171,174,175,176,178,180,184,185,186	33

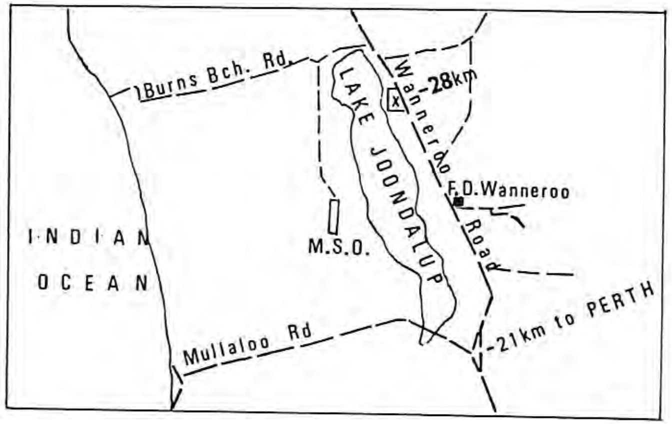
45	53	46	47	14	47	46	15	53	28	41	46	2	33	5	50
·119 49	15	·186 40	41	·148 31	40	·133 28	41	·185 2	31	·118 49	14	·176 41	46	·186 45	19
·169 5	31	·171 2	50	·161 2	50	·122 5	49	·158 5	40	·156 19	50	·166 49	40	·174 31	14
·154 28	19	·180 29	14	·136 33	19	·166 45	53	·146 47	45	·151 33	15	·180 47	15	·151 28	53
·186 2	47	·174 50	15	·177 41	28	·118 47	2	·185 33	19	·122 5	14	·177 19	41	·166 49	40
·166 46	53	·133 41	19	·146 33	50	·173 5	53	·151 45	49	·166 53	31	·118 45	53	·185 46	5
·167 28	33	·119 40	14	·156 15	49	·166 45	40	·148 15	2	·164 46	28	·186 14	15	·177 50	2
·148 45	31	·185 49	5	·162 46	19	·118 31	14	·133 41	50	·119 40	47	·168 31	28	·171 47	33
·162 53	33	·177 40	41	·156 49	40	·173 50	19	·174 46	47	·186 14	19	·154 14	15	·185 49	28
·158 45	50	·173 49	5	·186 15	28	·118 14	47	·146 41	5	·176 50	31	·180 46	33	·119 53	50
·180 31	14	·162 19	28	·118 2	53	·185 45	33	·168 53	33	·167 28	2	·174 40	45	·162 41	2
·185 47	46	·186 2	15	·171 5	31	·176 41	46	·148 15	40	·133 49	45	·123 47	31	·176 5	19
·123 2	5	·169 14	33	·164 28	15	·119 50	14	·180 41	2	·185 19	53	·148 46	53	·119 2	14
·154 53	28	·186 31	49	·148 47	53	·118 19	5	·167 45	47	·173 46	15	·164 33	41	·185 40	15
·166 45	50	·161 47	19	·133 46	49	·180 45	41	·164 28	5	·123 33	40	·158 19	28	·118 50	49
·169 46	41	·167 15	40	·123 33	31	·158 2	40	·166 49	31	·169 50	14	·186 5	45	·168 47	31

LAKE JOONDALUP SEED ORCHARD

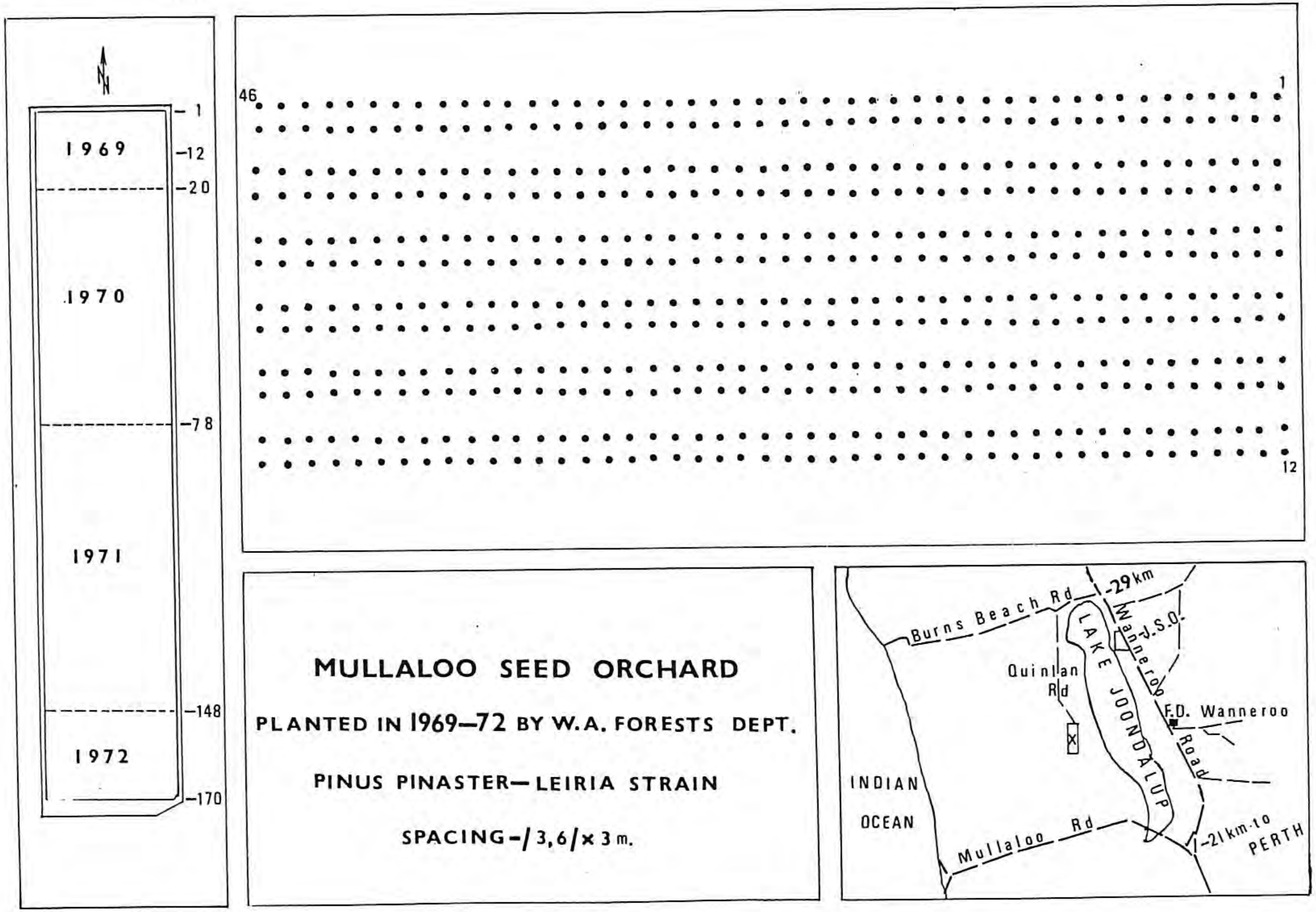
PLANTED IN 1963-64 BY THE W.A. FORESTS DEPARTMENT

PINUS PINASTER- LEIRIA STRAIN. SPACING - 6.7 x 6.7 m.





APPENDIX V Diagrammetric details of the Joondalup Seed Orchard.



MULLALOO SEED ORCHARD

PLANTED IN 1969–72 BY W.A. FORESTS DEPT.

PINUS PINASTER— LEIRIA STRAIN

SPACING–/ 3,6 /× 3 m.

APPENDIX VI Diagrammetric details of the Mullaloo Seed Orchard.

APPENDIX V11A

Tree form classification for progeny and provenance trials in 1974.

S **Straightness**

Very crooked, large sweep, severe lean, bend (spiral) bole	1
Crooked, slight sweep. Necessary to waste part of log in cutting operation	2
Average, some slight deviation, but can still cut single log without wastage	3
Nearly straight, but not perfect, no wood wasted	4
Very little, or no deviation from straight and vertical	5

B **Branching**

Very steep angled, very thick branches	1
Steep angle, thick branched	2
Moderate angled, thick-moderate branched	3
Moderate angled, moderate branched	4
Moderate angled, fine branching	5

T **Form**

Fork	1
Ramicorn	2
No leader	3
Twisted or damaged top	4
Normal	5

Trials measured

YS01, YS02, YS03, YS04, YS05, YS06, YS07, XS07.

APPENDIX V11B

Tree form classification for progeny and provenance trials used in 1975.

Stemform:	Normal	1
	Malform	2
	Fork	3
Straightness:	Perfect tree	1
	Nearly straight but not perfect	2
	Average (slight dev., but no wastage)	3
	Crooked (waste part of log)	4
	Extreme crooked, large sweep and kinks	5
Branching:		
Type	Uninodal	1
	Binodal	2
	Multinodal	3
Angle	Low angled, approx. 90°	1
	Intermediate - average	2
	High angled, steep	3
Thickness	Small	1
	Medium	2
	Heavy, Thick	3
Crown:		
	Well balanced, vigorous	1
	Well balanced, dormant	2
	Unbalanced, vigorous	3
	Unbalanced, dormant	4

Butt sweep, lean, bend:	Present	1	Absent	2
Ramicorn:	Present	1	Absent	2
Cones:	Present	1	Absent	2
Leader:	Present	1	Absent	2

Trials measured - YS08, YS09, YS10, XS12.

APPENDIX VIIC

Tree form classification for progeny trials used in 1976.

B. Butt sweep	1	Absent
	2	Very slight
	3	Slight, noticeable
	4	Marked
	5	Excessive
S. Stem sweep	1-5	As above. Note that lean is included as 2 points.
C. Crooks	1	Perfectly straight
	2	Straight; may have very slightdeviation
(General tree straightness, and ignores effects of butt sweep)	3	Average; slight deviation but no wasteage
	4	Crooked; not straight, waste part of log
	5	Extreme crooks

(Note: In analysis points 1 and 2 are grouped, and are considered as 'final crop' trees, and points 1, 2 and 3 are grouped and considered as 'acceptable crop' trees).

T. Branch thickness	1	Very small diameter branches
	2	Small diameter
	3	Average (for the population)
	4	Moderate size
	5	Large diameter branches

(Note: Branch diameter is related to the stem diameter).

A. Branch angle	1	Near to right angles 90°
	2	Flat, or low angle, approx 75°
	3	Average, approx 60°
	4	Above average, approx 45°
	5	High angled, ascending branches, 30°
F. Tree form	1	Normal
	2	Malformed
	3	Fork

D. Damage Physical damage to leader to be noted.

Trials measured - YS11A, YS13a, YS15, YS17, XS10.

APPENDIX V11D

Tree form classification for progeny trials
Used from August 1978 to May 1983.

B.	**Butt sweep**	1	Absent
		2	Very Slight
		3	Slight, noticeable
		4	Marked
		5	Excessive

S.	**Stem straightness**	1	Perfectly straight
		2	Straight; may have very slight deviation
	(General tree straightness, and ignores effects of butt sweep)	3	Average; slight deviation but no wastage
		4	Crooked; not straight, waste part of log
		5	Extreme crooks

Note, in analysis points 1 and 2 are grouped, and are considered as 'final crop' trees, and points 1, 2 and 3 are grouped and considered as 'acceptable crop' trees.

T.	**Branch thickness**	1	Very small diameter branches
		2	Small diameter
		3	Average (for the population)
		4	Moderate size
		5	Large diameter branches

Note, branch diameter is related to the stem diameter.

A.	**Branch angle**	1	Near to right angles
		2	Flat, or low angled, approx 75°
		3	Average, approx 60°
		4	Above average, approx 45°
		5	High angled, ascending branches, 30°

F.	**Tree form**	1	Normal
		2	Malformed
		3	Fork

Trials measured - From August 1978 to May 1983.

APPENDIX V11E

Tree form classification for progeny trials (BSTAF)
Revised January 1984.

B. Butt sweep

1 Nil to slight sweep
2 Slight sweep, easily noticeable
3 Moderate sweep
4 Severe sweep

S. Stem straightness (Stem straightness to be observed independently of the butt sweep)

1 Straight
2 Reasonably straight, slight sweep, etc
3 Not straight, crooked
4 Extreme crooks and sweeps

T. Branch thickness (Branch thickness must be related to stem diameter)

Branch/stem		
1	Small	Ratio of 0.3
2	Small to moderate	Ratio of 0.4
3	Moderate to large	Ratio of 0.5
4	Large diameter	Ratio of 0.6

A. Branch angle

1	Flat angle	75° - 90°
2	Low to moderate angle	60° - 75°
3	Moderate angle	45° - 60°
4	High angle ascending	30° - 45°

F. Tree form

1 Normal
2 Ramicorn
3 Fork
4 Fork-multiple

Trials measured - From April 1984.

APPENDIX VIII

Production seed yields registered for the *Pinus pinaster* improvement program.

YEAR RECEIVED	ORIGIN	WEIGHT (kg)	SERIAL NUMBERS
1968	Joondalup S.O.	13	-
1969	Joondalup S.O	51	5008
1970	Neaves Scion Arb.	56	5007
1970	Joondalup S.O.	70	5020
1971	Joondalup S.O.	259	5047
1972	Joondalup S.O.	142	5060
1973	Joondalup S.O.	109	5063
1974	Joondalup S.O.	160	5068
1975	Joondalup S.O.	116	5073
1975	Mullaloo S.O.	24	5072
1976	Joondalup S.O.	155	5083
1976	Mullaloo S.O.	77	5084
1977	Mullaloo S.O.	103	5088
1978	Mullaloo S.O.	148	5096
1979	Mullaloo S.O.	9	7901
1981	Mullaloo S.O.	131	8014
1981	Mullaloo S.O.	152	8015
1982	Mullaloo S.O.	121	D647
1982	Mullaloo S.O.	16	D648
1983	Mullaloo S.O.	25	D649
1983	Mullaloo S.O.	83	D650
1984	Mullaloo S.O	77	D643
1984	Mullaloo S.O.	95	D644
1985	Mullaloo S.O.	92	D894
1985	Mullaloo S.O	36	D895
1987	Mullaloo S.O.	19	D1097
1988	Mullaloo S.O.	17	D1310
1989	Mullaloo S.O.	257	D1370
1990	Mullaloo S.O.	107	9078
1992	Mullaloo S.O.	55	93408

APPENDIX IX

Representation of standard families and the routine control (RT) in field trials

TRIAL	FAMILY					
No.	S02	S01	S17	S25	S32	RT
XS01		No standards				
XS02		No standards				
XS03		No standards				
XS04		No standards				
XS05	*					
XS06		No standards				
XS07		No standards				*A
XS08		No standards				*A
XS09	*					*A
XS10	*				*	*B
XS11	*				*	*B
XS12					*	*B
XS13			*			
XS14			*			
XS15			*			
YS01	*					*A
YS02	*	*				
YS03	*	*				
YS04	*	*	*	*		
YS05	*	*		*		
YS06	*	*				
YS07	*	*	*			
YS08	*			*		*B
YS09	*			*		*B
YS10	*			*		*B
YS11	*	*	*	*		*B
YS12	*		*	*		*B
YS13	*	*	*	*		*B
YS14	*		*	*		*B
YS15		*				*B
YS16	*		*	*		*B
YS17		*	*			
YS18	*	*	*	*		*C
YS19	*	*	*	*		*C
YS20	*	*				*C
YS21	*	*	*			*C
YS22	*	*	*			*C
YS23	*		*	*		*C
YS24	*	*	*			*C
YS25	*	*	*	*		
YS26	*	*	*			
YS27						
YS28	*	*	*		*	*C
YS29		*	*		*	*C
YS30	*	*	*		*	*C
YS31	*	*	*		*	*C
YS32	*	*	*		*	*C
YS33	*		*		*	
YS34		*				
YS35			*			
YS36			*			*C
YS37	*				*	*C
YS38	*				*	*C
YS39	*	*	*	*		
YS40	*	*	*	*	*	*D
YS41	*	*	*	*	*	*D
YS42	*	*	*	*	*	
YS43	*	*	*	*	*	
YS44	*			*	*	*D
YS45	*	*	*	*		*D
YS46	*	*	*	*		*D
YS47	*	*	*	*		*D
YS48	*	*	*	*		*D
YS49	*	*	*		*	*D
YS50	*		*		*	*D
YS51				*	*	*D
YS52				*	*	*D
YS53				*	*	*D
YS54	*		*			*D
YS55		No standards				
YS56	*		*			*D
YS57	*		*	*		
YS58	*		*	*		
YS59	*		*	*		
YS60	*		*	*		
YS61	*		*			
YS62	*	*	*			
YS63	*	*	*			
YS64	*			*		*E
YS65	*		*	*		*E
YS65	*		*	*		*E
YS66			*	*		*E
YS67		No standards				
YS68		No standards				
Total	**57**	**36**	**45**	**32**	**25**	**48**

Routine controls
A - S3056
B - S3697
C - S4076
D - S5000
E - S5960

APPENDIX X
Average height at age 3.5 years of 15 Families
(8 parents) ranked in order of mean height (m) over
four WA locations. Trials were planted in 1969.

Family	Gnangara		Yanchep		Manjimup		Hamel		Mean	
	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht	Rank	Ht
E31xE40	1	2.22	4	3.41	2	3.83	4	3.13	1	3.15
E50xE33	9	1.82	2	3.50	3	3.62	1	3.41	2	3.09
E50xE40	5	1.99	6	3.39	1	3.95	7	3.08	3	3.08
E50xE14	3	1.99	1	3.63	8	3.37	3	3.19	4	3.00
E31xE14	2	2.05	9	3.34	4	3.61	11	2.92	5	2.98
E46xE40	14	1.63	8	3.36	6	3.56	2	3.38	6	2.98
E53xE40	8	1.83	10	3.33	5	3.60	5	3.13	7	2.97
E46xE33	12	1.75	3	3.49	7	3.49	9	2.97	8	2.92
E31xE33	4	1.94	11	3.32	12	3.19	12	2.91	9	2.84
E53xE33	6	1.84	5	3.40	10	3.34	15	2.63	10	2.80
E46xE14	7	1.84	12	3.23	13	3.12	8	2.99	11	2.80
E53xE14	13	1.69	7	3.37	9	3.35	14	2.70	12	2.78
E49xE33	15	1.55	13	3.15	14	3.10	6	3.09	13	2.72
E49xE40	10	1.78	15	3.04	15	3.10	10	2.95	14	2.72
E49xE14	11	1.77	14	3.07	11	3.20	13	2.83	15	2.72
Mean		1.84		3.34		3.43		3.02		2.91
LSD		0.30		0.19		0.29		0.50		0.17
Parent										
E50	2	1.90	1	3.50	1	3.64	1	3.23	1	3.07
E31	1	2.07	3	3.36	2	3.54	3	2.98	2	2.99
E46	4	1.74	4	3.36	4	3.39	2	3.11	3	2.90
E53	3	1.79	2	3.37	3	3.43	5	2.82	4	2.85
E49	5	1.70	5	3.09	5	3.15	4	2.96	5	2.72
LSD		0.17		0.11		0.17		0.29		0.10
E40	1	1.87	3	3.31	1	3.61	1	3.13	1	2.98
E33	3	1.78	1	3.37	2	3.35	2	3.00	2	2.88
E14	2	1.87	2	3.33	3	3.33	3	2.93	3	2.86
LSD		0.13		0.09		0.13		0.2		0.07

APPENDIX XI

Local *P. pinaster* families planted at locations outside Western Australia. Comparable local test areas are included. Numbers refer to year of planting.

PEDIGREE SN	CROSSING	VICTORIA RENNICK	KENTBRUCK	GLENCOE	FRI MOWAT	ACT JERVIS BAY	N.Z	STH. AFR.	WEST AUSTRALIA GN	YN	H	M
17	E40xE41	69	69	-	-	-	S		69	69		
20	E28xE41			69	69	69			69	69		
32	E19xE40	69	69				S	70	70	70		
54	E19xE14	69	69				S	70				
56	E19xE33	69	69				S	70				
57	E19xE29	69	69				S	70				
63	E40xE33	69	69						70			
86	E08xE02			69	69	69						
88	E11xE40			69	69	69						
89	E12xE14			69	69	69						
90	E12xE40			69	69	69						
95	E16xE14			69	69	69						
96	E16xE40			69	69	69						
97	E18xE02			69	69	69						
98	E18xE40			69	69	69						
99	E19xE154	69	69	69	69	69	S	70				
100	E19xE182	69	69	69	69	69	S	70	70	70		
101	E21xE14			69	69	69						
103	E22xE02			69	69	69						
104	E22xE40			69	69	69						
111	E28xE182			69	69	69						
119	E35xE02			69	69	69						
120	E37xE02			69	69	69						
121	E37xE40			69	69	69						
122	E38xE02			69	69	69						
123	E39xE02			69	69	69						
124	E40xE15	69	69					70				
125	E40xE182	69	69	69	69	69	S	70				
128	E52xE02			69	69	69						
129	E52xE40			69	69	69						
130	E54xE02			69	69	69						
141	E46xE14	69	69	69	69	69		70	69	69	69	69
144	E53xE14	69	69	69	69	69		70	69	69	69	69
146	E18xE15	69	69				S	70				
155	E53xE15	69	69				S	70	70	70		
157	E53xE182	69	69				S	70	70	70		
168	E46xE33	69	69	69	69	69		70	69	69	69	69
169	E49xE33		69	69	69			69	69	69	69	
170	E50xE33			9	69	69			69	69	69	69
171	E53xE33	69	69					70	69	69	69	69
173	E19xE34	69	69				S	70				
184	E46xE40		69	69	69			69	69	69	69	
187	E53xE40	69	69				S		69	69	69	69
188	E15xE41		69	69	69			69	69			
181	E46xE41								69	69	69	69
184	E53xE41	69	69	69	69	69	S		69	69	69	69
202	E40xE154	69	69				S	70				
205	E46xE154	69	69				S	70	70	70		
209	E53xE154	69	69						70	70		
215	E46xE182	69	69				S	70				

APPENDIX XII

Rating of clones for general combining ability.

EXCELLENT	VERY GOOD	GOOD	AVERAGE	POOR	VERY POOR	NOT CLASSIFIED
E05	E45	E02	E14	E08	E09	E122
E16	E48	E58	E17	E11	E12	E125
E29			E18	E24	E13	E169
E31	E115	E101	E21	E29	E15	E179
E33	E117	E104	E32	E52	E25	E185
E40	E124	E110	E46	E54	E26	
E41	E129	E118	E47	E57	E28	
E50	E132	E121	E53	E59	E34	
	E134	E127			E35	
E114	E143	E128	E103	E102	E37	
E119	E158	E135	E105	E106	E38	
E136	E160	E139	E108	E107	E39	
E149	E164	E150	E109	E113	E55	
E152	E166	E153	E111	E123	E56	
E154		E167	E126	E130		
E162		E168	E131	E137	E112	
E163		E181	E133	E145	E120	
E165			E147	E157	E138	
E182			E148	E172	E140	
			E161	E174	E141	
			E170	E183	E142	
			E177		E144	
			E178		E146	
			E180		E151	
					E156	
					E159	
					E171	
					E173	
					E175	
					E176	
					E186	