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Provenance comparisons of *Pinus pinaster* Ait. in Western Australia

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SUMMARY

Results from field trials established during the period 1964 to 1974, support earlier research in confirming that Leiria, in Portugal, is the most vigorous provenance of *Pinus pinaster* when grown under Western Australian conditions. Relative to other provenances tested, it also has superior drought resistance but low resistance to frost.

The Corsican race has outstanding qualities in stem straightness and apical dominance. Differences between provenances in branch angle and branch size were not as significant as expected. Selection within the Leirian provenance, or any provenance, is probably the best procedure for improving branching in the species.

Leirian populations are very defective in apical dominance and a high percentage of trees exhibit forks or ramicorns. Improvement in this character with selection in Leirian populations has been limited. Inter-provenance crossings with the Corsican origin may have to be considered in future but current results indicate that such a cross would lead to significant losses in volume production.

Fecundity varies with provenance from high production of cones within four years of planting for trees of Tunisian origin to a general sparseness of cones throughout the life of Corsican trees. In Western Australia, Leirian trees produced cones at a younger age than those from Landes or Corsica. Genetic control of time of flowering was confirmed. Flowers in trees of Leirian origin ripened earliest, followed by flowering in the French Landes, Tunisian, Italian and Corsican provenances, in sequence as spring proceeded. A wide variation in flowering time was shown for clones within any one geographic group.

Limited comparisons of wood properties between provenances indicated that the Leirian provenance, with relatively high basic density and low grain deviation, was the best suited for production of sawn timber. Therefore, breeding with this provenance would not compromise the future quality of the wood produced.

Trials with inter-provenance crosses between plus trees of Leirian, Landes and Corsican origin demonstrated the inheritance and dominance of such racial characters as vigour in the Leirian and stem straightness and apical dominance in the Corsican provenance. Crosses between Landes and Leiria may provide a hybrid of vigour approaching that of Leirian trees. Similarly, the combination of straightness and apical dominance was achieved in Leiria by Corsican crosses but vigour was low.

Over the range of sites tested in Western Australia for provenance variation, crosses between clones of the Leirian provenance were significantly superior in diameter and height growth to those of Leiria by Landes and Leiria by Corsica. There was, however, a tendency for the advantage in diameter growth of the Leirian provenance to decrease as plantings were extended to the south where conditions were cooler and wetter.

Geographic similarity and the distinctiveness of provenances were clearly demonstrated by canonical discriminant analysis of attributes measured in the trials. Improvement appears to be obtainable by concentrating on the Landes provenance for cooler, frost-prone areas and on the Leirian provenance for warmer and drought-prone sites.

For Western Australia, all improvement required within the range of variation of the species is being obtained from selection and crossing within the Leirian population.

THE PROBLEM AND APPROACH

This paper reviews the knowledge of variation in *Pinus pinaster* Ait. of value to the commercial future of the species in Western Australia and presents previously unreported results from field trials begun in the period 1964–1967. The objective is to document these local investigations and indicate areas which could be of importance to the local improvement program for the species.

The presentation is in four sections. The first section introduces the history of the species in Western Australia, outlines the nature of investigations and provides a brief literature review of racial variation in the species. The second section describes eleven field trials and is intended for only those concerned with the details of *P. pinaster* provenance testing. Differences in flowering time and fruitfulness of several provenances considered in the local crossing program are covered briefly in a third section. The final section considers the relevance of provenance variation to tree improvement in the State and the validity of the investigation.

Introduction

Pinus pinaster, the maritime pine (also formerly known as cluster pine), and its varied forms have been of interest to forestry in the south-west corner of Western Australia since early colonial days. European colonizers of the similar climatic provinces in both South Africa and south-west Australia noted the paucity of natural softwoods for the local economy, and extensive tracts of low quality forest on sandy soils, and treeless areas. Outstanding examples of afforestation on similar sands and in similar climates in Gascony, France, during the period 1787 to 1864 (Harle 1920; Guinaudeau 1964) were conducive to early afforestation attempts in Cape Province (Duff 1928) and later, in Western Australia.

The relevance of *P. pinaster*, and the possible significance of its geographic variation, to forestry in Western Australia was assessed in 1916. Hutchins, a forester with experience in India, South Africa and East Africa and professional training in Europe was invited to comment on the forestry situation in the State. He reported (Hutchins 1916)

> 'The climate of the Western Australian jarrah forest is sufficiently similar to southern France but more favourable to cluster pine (*Pinus pinaster*). It is in fact the exact climate of Leiria in Portugal, where I saw cluster pine at its best...'.

Hutchins took pains to distinguish between the different growth forms of the species in France and Portugal and recommended the use of seed from the forest of Leiria in Portugal.

Variation in this species and the importance of seed origin to its forestry potential in the southern hemisphere was first described by Duff (1928) and elaborated, from experience with field trials in South Africa, by Rycroft and Wicht (1947). Duff's report of the species in both its natural range and in the developing plantations in South Africa was well received in Western Australia. Reports of expressions of racial differences in the species observed in local plantation trials were published by Perry (1940, 1949). Quantitative evidence for early provenance evaluations in the State was collated by Hopkins (1960) who also argued the value of a tree improvement program based on Portuguese seed.

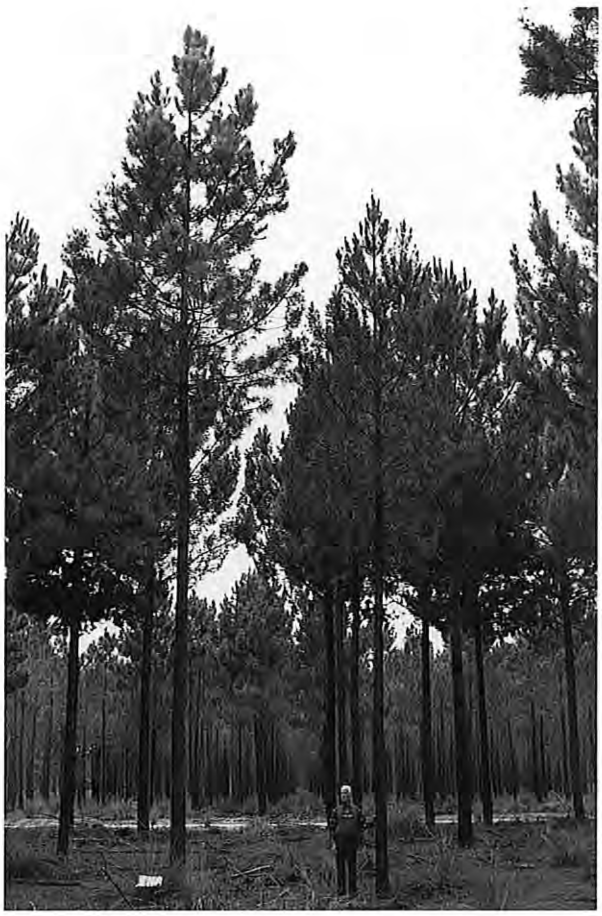

Figure 1. Representative samples of the Leirian (left) and Landes (right) provenances at age 21 years in trial YS08, Gnangara plantation.

Research in evaluating the status of geographic races and provenance variation for *P. pinaster* (Figs 1 and 2) has been carried out at various locations in both the northern and southern hemispheres (Destremau *et al.* 1982). Major aspects of geographic variation in the species are now well understood. In France and Western Australia in particular, knowledge of variation and heritability of characters is being used to improve the plantation tree in such attributes as volume production, stem straightness, branch angle and size, drought tolerance, frost resistance, and wood density, fibre length, grain deviation and resin content.

Geographic Races

The most recent and comprehensive article reviewing provenance variation in *P. pinaster* is by Destremau *et al.* (1982). They associated variation within the species with dispersion and isolation following past changes of climate. During the Quaternary period the distribution of the species in western and southern Europe, under glaciation, was discrete within mid-elevations on the continental massif. As a result of geographic barriers, isolated populations tended to develop differences in characteristics. Remnants of the original domain of the

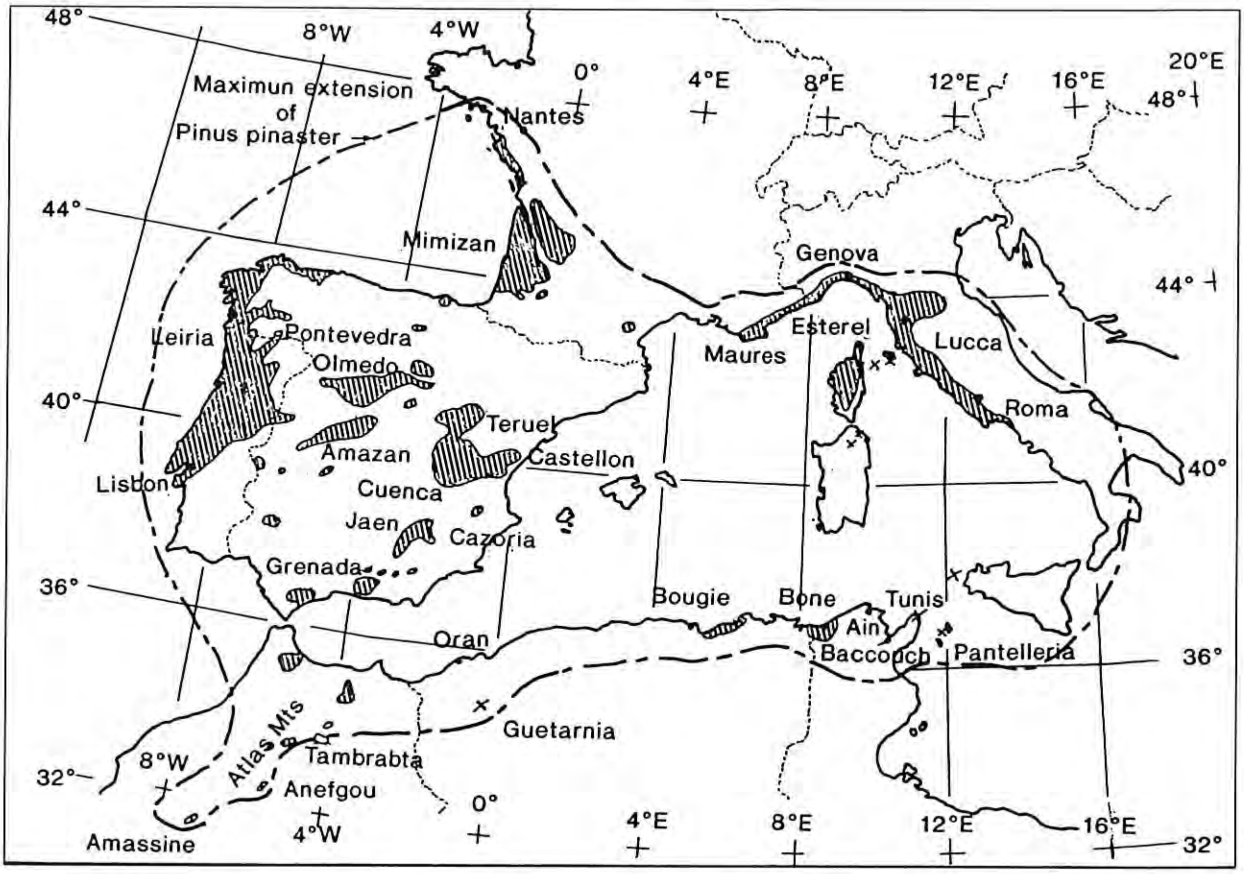

Figure 2. Map showing the natural distribution of Pinus pinaster. *The shaded sections and crosses mark the concentrations of the species (After Destremau* et al. *1982).*

pine in the western Mediterranean area are on the massifs of Maures, Esterel, Corsica, Sardinia, Edough, Ain Draham, Rif, Grand Atlas, Sierra Nevada, the Iberian mountains, the piedmont of the Pyrenees and the sandy coastal plains along the Atlantic (Fig. 2).

Some authorities believe that maritime pine also occurred naturally on islands of the Adriatic sea along the Yugoslav coast and down to Greece. Recent indications are, however, that all maritime pine present in Yugoslavia was introduced within recent historical times.

Destremau *et al.* (1982) suggested that the centre of dissemination of the species was the mid-altitudinal areas of the Iberian Peninsula, at the junction of the Mediterranean and Atlantic climatic currents. According to palaeo-botanical studies, colonization of the lower Gascogne plains was accomplished recently either from mountain refuges of Galicia or from isolated sites in Catalogne. For palynologists there is little doubt that the Gascogne extension can only be dated to the recent post-glaciation period.

Destremau *et al.* (1982) agreed with Resch (1974) that the species consists of five major races geographically separated by physical barriers or sharply contrasting microclimates. These races are:

1. The Atlantic group, which occupies the coastal plains and seaboard of the Atlantic Ocean from south of Lisbon in Portugal to the mouth of the river Loire (Nantes) in France.
2. The provincial Mediterranean group, which is localized to the coastal sites along the northern coast of the Mediterranean Sea from Tarragona in Spain to Tivoli, just east of Rome, in Italy.
3. The Corsican group, restricted to the islands of Corsica and Sardinia.
4. The Continental group, of the Iberian mountain regions, to which are attributed a large variety of Spanish, Moroccan and Portuguese ecotypes. These ecotypes occupy very special ecological niches which are the local provenances of the divides of the natural surfaces of the quaternary glacial periods.
5. The North African coastal group, restricted to coastal areas from Bougie in Algeria to Pantelleria off north eastern Tunisia.

The grouping is based on consistent expressions of tree vigour and phenotypic appearance recorded by many observers and detailed comparative trials (Duff 1928; Rycroft and Wicht 1947; Perry 1949; Hopkins 1960; Sweet and Thulin 1962; Illy 1966; Rodriguez 1966; Resch 1974; Alazard 1982; Matziris 1982). Recently, effective replication of provenances within trials and comparisons of a wide range of provenances and controlled crosses (Alazard 1982) have provided quantitative results which relate to genetic control of racial attributes.

Bernard-Dagan *et al.* (1971) have provided a consistent identification procedure for genetic separation of provenances on the basis of monoterpene contents of the wood and cortical tissues of mature trees. Their studies and recent work (Baradat *et al.* 1979) have identified distinctive chemical compositions for the racial groupings 1, 2, 3 and 4 described above but did not sample Italian (group 2) and the north African (group 5) provenances. They were also able to distinguish clearly between Portuguese and Landes provenances on the basis of the amount of D3-carene contained in the cortical tissues.

Perry (1949) differentiated between Portuguese and Landes groups on the basis of genetic control of flowering times and Destremau *et al.* (1982) also recorded these differences in flowering times for comparative conditions in Europe.

Evaluation in Western Australia

Early plantings of *P. pinaster* in Western Australia clearly demonstrated the superiority of trees derived from the forests of Leiria, in Portugal, for commercial plantations (Perry 1940; Hopkins 1960). Since 1942 all Western Australian plantations have had a Portuguese seed origin.

A genetic improvement program for *P. pinaster* in Western Australia was begun in 1957 (Hopkins 1960; Perry and Hopkins 1967; Hopkins 1969; Hopkins and Butcher 1993). The program concentrated on the Portuguese provenance with the aim of improving stem straightness, branching characteristics and uniformity of the commercial tree. Renewed interest in other provenances was also focused on quantitative aspects of provenance testing and species variation, as no statistically controlled trial or useful gene bank for the species was available in Australia. The possible contribution of genes from other provenances to improvement in stem straightness, hybrid vigour, branch size, spiral grain, wood density and drought resistance required consideration.

A series of provenance tests and inter-provenance crossings was undertaken during the early phase of the *P. pinaster* breeding program (Fig. 3). This compared growth under a range of conditions in the field and evaluated wood properties. Wherever possible the trials included seed from trees of superior phenotype (plus-trees), selected by international agencies. Seedling studies of provenances were used to evaluate drought resistance (Hopkins 1971b).

Details of the time of flower receptivity for three provenances were recorded as part of the controlled pollination phase of the species improvement program.

Comparisons of major wood properties of provenances, from trees sampled in Western Australia or Portugal, were carried out in arrangement with the Commonwealth Scientific and Industrial Research Organisation (Nicholls *et al.* 1963; Nicholls 1967; Nicholls 1968).

The original trial nomenclature has been used in this report because it is relevant to the local workers in the field. The original designation for Portuguese (Leirian provenance) plus-trees of E (elite) followed by a number has been retained. Similarly, plus-trees of Landes origin are designated with an L and those of Corsican origin with a C.

FIELD TRIALS

Introduction

This chapter describes in detail the procedure and results of eleven field trials established from 1964 to 1967 to demonstrate the performance of provenance groups under a range of field conditions (Table 1). Four of these trials (3/65, XS09, XS12, XR1) were designed to show differences between bulked collections of major provenance groups. The remaining seven included half-sib (open pollinated) or full-sib (control pollinated) material, particularly of Portuguese and French origins which are most favourable to Western Australian conditions, to demonstrate the range of variation within these two provenances. They were also intended to provide material in which future selection for controlled crossing might be undertaken. Three of these seven trials included inter-provenance crossings together with improved stock from a recently established seed orchard to indicate the potential of hybrids within the improvement program.

Field trials were replicated in either Latin Square or randomized block designs. Most were established with seedlings raised in tubes to obtain high survival on planting out and remove effects of nursery treatment and refilling from the results. The initial trials with bulked provenance groups employed square plots of 36 or more plants as the unit of comparison. Later trials with half-sib or full-sib families and tubed stock used line plots with 5 or 10 trees, but with increased replication.

In all trials a commercial seed batch imported from the Portuguese forests of Leiria for general plantation establishment, was included. This is referred to as the routine seed batch and provided a control to link provenance comparisons between trials.

Assessments for characteristics of form were on the basis of standard scores as depicted in Table 2. Results were expressed either as the percentage of stems in the population with average or better stem straightness (i.e. percentage in classes 1, 2, 3) or the mean score (arithmetic mean of points awarded). The percentage of population is more acceptable to field workers as a stand parameter and is used here. For analysis all percentages were transformed to angle arcsin (the angle whose sine is the square root of the percentage).

The trials were conducted over the period 1964–1985. With over 20 years elapsed since the last trial was established results are conclusive and can be confidently interpreted to apply to mature stands.

Figure 3. Early growth of provenances at Gnangara plantation. The comparisons are Italian-Portuguese (top left), Portuguese-Landes (top right), Portuguese-Corsican (bottom left), and Tunisian-Portuguese (bottom right). The first three comparisons are in trial 3/65 at age 5 years; the fourth is in trial XS09 at age 4 years.

General Comparisons

Trial 3/65 – Comparison of Commercial Seed Lots from Portugal, France, Corsica and Italy

Establishment

Trial 3/65 was established in 1964 with seedlings from five bulk provenance seed lots to statistically evaluate differences between the growth of provenances in Western Australia. Earlier trials had suffered from lack of replication within sites and from thinning. A fire in the main demonstration area in compartment 19, at Gnangara plantation further limited the use of existing plots.

Provenances – The five bulked seed lots were from Portugal (Leiria), France, Corsica, and Italy as follows:

Leiria R. Seed lot number S2866. One kilogram was received from Portugal in 1962, reputed to be collected from the Forest of Leiria.

Leiria 2. Source unknown. Mistakenly used as the provenance from Lucca (Italy). Probably part of the commercial Leiria batch used for plantation establishment in 1964.

TABLE 1

Description and location of *Pinus pinaster* provenance tests established in Western Australia since 1960.

TRIAL NO.	LOCATION	YEAR PLANTED	PROVENANCE					REPLICATION	MEASUREMENT			
			LEIRIA	LANDES	CORSICAN	TUNISIAN	OTHER	TREES/PLOT IN BRACKETS	HT.	DIAM.	FORM	DROUGHT
3/65	Gnangara	1964	2 B	1 B	1 B		Italian	(128) x 5	1969		1969	
							1 B		1973	1973		
									1975	1975	1975	
									1977	1977		
									1985	1985		
XS09	Gnangara	1966	1 FS			24 HS	Spanish	(10) x 8	1970			
			1 B				2 B		1976	1976		
			12 HS									
XS11	Gnangara	1967	4 FS	14 HS				(10) x 10	1971			
			1 B									
									1976	1976		1977
XS12	Yanchep	1967	2 FS	2 HS	4 B			(36) x 5	1971			
			1 B						1975	1975	1975	
			1 HS						1977	1977		1977
									1987	1987		
YS08	Gnangara	1967	14 FS	3 HS				(10) x 10	1971			
			1 B	1 FS					1975	1975	1975	
			1 HS							1980		
YS09	Yanchep	1967	9 FS	8 HS				(10) x 10	1971			
			1 B	1 FS					1975	1975		1977
			1 HS							1980		
YS10	Mundaring	1967	8 FS	10 HS				(5) x 20	1971			
			1 B							1976		
			1 HS									
XR1	Yanchep	1966	1 FS	4 FS		18 HS	Italian	None	1979	1979	1979	1979
			7 HS				Lucca					
			2 B				N Spain					
							W Spain		(Part)	(Part)	(Part)	
YS51	Gnangara	1974	10 FS	10 FS	8 FS			(5) x 10	1983	1983	1983	
			2 B									
YS52	Yanchep	1974	9 FS	9 FS	8 FS			(5) x 10	1978			
			2 B						1983	1983	1983	
YS53	Busselton	1974	9 FS	9 FS	8 FS			(5) x 10	1978			
			2 B						1983	1983	1984	

Seed lots: B bulk HS half-sib; FS full-sib.

TABLE 2

Scoring scales used for assessment of tree form characteristics in early provenance trials.

STEM FORM:	Normal		1
	Malform		2
	Fork		3
STRAIGHTNESS:	Perfect Tree		1
	Nearly straight but not perfect		2
	Average (slight deviation but no wastage)		3
	Crooked (waste part of log)		4
	Extremely 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	

Landes. Seed lot number S2865. The batch was received in 1962 as being typical of the Landes forests.

Corsica. Seed lot number S2897. Received in December 1962. It was collected in the Antisanti region. Elevation 750 m. Latitude 42°9'. Longitude 9°21'E. Annual rainfall 880 mm. Annual average air temperature 12°C.

Italian. Seed lot number S2864. Origin Italy.

Design – The provenances were established in a 5 x 5 Latin Square design with square plots of 128 trees (8 rows with 16 trees in each row) planted at the rate of 2240 stems per hectare (stems ha^{-1}).

Procedure – The trial was planted in June 1964 with 1-0 nursery stock on a high quality site in Walton Block, Gnangara plantation. The site was wet at time of planting owing to extensive clearing and an exceptionally wet winter. Some refilling was carried out in 1965.

The plants were thinned in 1970 to 735 stems ha^{-1} (from 128 to 42 in each plot) and in 1977 to 368 stems ha^{-1} (from 42 to 21 in each plot). Fertilizer was added as a spot application of superphosphate at planting, 500 kgha^{-1} of superphosphate was broadcast

TABLE 3

Seedling mortality of provenances in trial 3/65 in the two years after planting in June 1964. Refilling to original numbers was carried out in June 1965.

PROVENANCE	NUMBER PLANTED JUNE 1984	PERCENTAGE MORTALITY 1965	1966
LeiriaR	640	14.7	11.6
Leiria2	640	13.4	11.1
Landes	640	5.3	7.0
Corsican	640	4.4	5.9
Italian	640	4.2	5.2

in 1973 and 500 kgha^{-1} of Agras (NP) was broadcast in 1978.

Pruning was carried out in 1970 (to 2 m), 1974 (to 3 m) and 1977 (to 4 m).

Measurement – Tree height and diameter at breast height (d.b.h.) were measured in 1969, 1973, 1975, 1977 and 1984. Branch angle, number of whorls and flowering characteristics were assessed in 1969 and a major assessment of form and branching was carried out in 1975. The scoring system in Table 2 was used in assessing tree form.

Results

Seedling survival – Results for seedling deaths in each of the two years following planting are set out in Table 3.

Height and diameter – Means for height, diameter and volume measurements are presented in Table 4. The provenances have separated into two distinct groups – the faster growing Leiria R and Leiria 2 and the slower growing Landes, Corsican and Italian provenances. The superiority of the former two is highly significant under the trial conditions.

Form – Results for form and flowering characteristics for trial 3/65 at ages 5.5 and 10.5 years are listed in Tables 5 and 6, respectively.

The counts of trees with or without cones or pollen development were expressed in Table 5 as a percentage of the total in each plot and transformed to angle arcsins for analysis. Differences between provenances for height growth and percentage of trees with cones or pollen were highly significant (.01 level), but those for branch angle and number of branches per whorl were not. In Table 6 variation in frequency of normal crowns, fine branches and butt sweep was not significant while that of binodal branching was significant at the .05 level. Differences in all other traits were highly significant (.01 level).

Portuguese provenances developed cone and pollen crops earlier than the others (Table 5).

TABLE 4

Growth of height, diameter and volume of provenances in trial 3/65.

PROVENANCE	10.5 YEARS			20.5 YEARS		
	HEIGHT (m)	DBHOB (cm)	VOLUME (m^3)	HEIGHT (m)	DBHOB (cm)	VOLUME (m^3)
LeiriaR	8.7a	13.1a	31.2a	15.0a	26.9a	116.3a
Leiria2	8.3a	12.7ab	28.9a	14.8a	25.7a	102.6a
Corsican	6.0b	10.4bc	14.4b	11.1b	21.8b	55.2b
Landes	6.0b	10.1c	14.3b	10.6b	20.9b	50.6b
Italian	5.5b	9.8c	11.8b	9.5c	19.9b	40.6b
LSD .05	0.4	1.0	10.0	0.9	2.9	22.5

[a] Measurements with similar alphabetic letters are not significantly different.

TABLE 5

Branching and flowering traits of provenances in trial 3/65 at 5.5 years of age.

PROVENANCE	MEAN HEIGHT (m)	PERCENTAGE (ARCSIN TRANSFORMATION) TREES WITH		BRANCH ANGLE IN WHORL AT 1.3 m		NUMBER OF BRANCHES /WHORL
		CONES	POLLEN	LARGEST	SMALLEST	
LeiriaR	3.7	37.6a	81.5a	66.0	44.2	4.9
Leiria2	3.8	38.7a	81.2a	66.4	43.8	4.9
Landes	2.6	2.3c	12.1c	62.3	40.8	5.4
Corsican	2.7	1.1c	20.4c	61.7	40.6	5.5
Italian	2.5	16.7b	45.9b	63.5	44.0	5.1

TABLE 6

Form and branching traits of provenances in trial 3/65 at age 10.5 years.

PROVENANCE	MEAN HEIGHT (m)	PERCENTAGE (ARCSIN TRANSFORMATION) OF TREES WITH								
		CONES	LEAN	BUTT SWEEP	RAMI-CORN	FINE BRANCH	STEEP BRANCH	BI-NODAL BRANCH	STRGT STEMS	NORMAL CROWN
LeiriaR	8.7a	51a	51a	29	34a	27	34a	80a	35b	68
Leiria2	8.3a	38b	52a	36	29ab	27	30a	80a	35b	70
Landes	6.0b	18c	25b	36	20b	27	15b	47b	49a	76
Corsican	6.0b	20c	32b	28	7c	27	18b	69ab	47a	72
Italian	5.5c	48a	44a	39	22b	25	20b	80a	17c	62
LSD .05	0.4	10	12	NS	10	NS	6	24	10	NS

Discussion

The relatively high seedling mortality of the Portuguese provenances (Table 3) is normal to Western Australian experience under these conditions. It has always been the most difficult of provenances to germinate and hand plant in the field. Under operational conditions good nursery practice, proper and extensive site preparation and machine planting have resulted in survival values consistently over the 90 per cent mark. Whenever hand planting is required, however, the project may be subject to high losses. For this reason tubed stock, which provided near to 100 per cent survival, was used in all other important trials within the improvement program.

Poor seedling survival of the Atlantic provenances was reported by Sweet and Thulin (1962) in New Zealand trials. Matzyris (1982) recorded failure of Portuguese seedlings owing to frost at one trial site in Greece but the provenance appeared to have similar early survival to three others compared at six further locations. Difficulty in seed handling and obtaining good seedling survival was considered to be an important attribute of the Portuguese provenance and was given major attention (Hopkins 1971a) in the local improvement program.

The results for height, diameter and volume growth and the general aspects of stem form support previous findings in Western Australia (Hopkins 1960). The Italian provenance is the slowest growing and the one of poorest form from the commercial viewpoint. The Landes and Corsican provenances have similar height and diameter growth rates but generally are superior in stem form and crown characteristics. The Corsican is outstanding in stem straightness and crown and branch symmetry. The Portuguese provenances are the most vigorous, significantly so, but defective in the percentage of ramicorns, high branch angle and upper stem straightness.

The form assessment separated the Portuguese and Italian from the Landes and Corsican provenances. The first pair have the poorest form with a relatively large percentage of ramicorns (large branches competing with the leader), leaning stems, high-angled branching and a lower percentage of straight stems. The Landes and Corsican groups have a high percentage of straight stems, well-shaped crowns and flat branching characteristics. However, the Corsican differed from the Landes through its lower frequency of ramicorns.

The Portuguese provenances were the earliest to produce cone and pollen crops under local conditions (Tables 5 and 6). The Landes and Corsican provenances were significantly later in this respect. The results indicate that precocity of flowering is genetically controlled and the characteristic has developed differently throughout the natural distribution of the species.

The Landes provenance had a lower proportion of binodal trees. This is not in accord with previous experience with the two provenances in Western Australia where the reverse situation was considered to be more probable. Differences in interpretation in assessment are possible and it should be noted that in the current data no multinodal stems (Class 3) were recorded in the assessment. All were classed as uninodal or binodal. Later it will be shown that the Landes seedlot in this trial had a close affinity with the Corsican provenances.

Trial XS12 – Intra- and Inter-Provenance Variation within Seed lots from Portugal, France and Corsica at Yanchep

Establishment

In 1967, availability of seed of reliable and selected sources in the Portuguese, Landes and Corsican races allowed for a trial design to compare variation both within and between provenance groups. The trial was also designed for establishment on limestone sands of the Spearwood dunes system (McArthur and Bettenay 1960) which represented much of the future planting area for the species. These limestone sites, with lower rainfall and less accessible ground water, are more drought prone. Prior to this, trials had been conducted mainly on deep grey sands with an accessible water table on the better sites.

Provenances – The trial incorporated 4 Portuguese seed lots, 2 Landes lots and 4 Corsican lots as follows:

1 Leiria E5xE40 – a controlled crossing of two plus parents selected in W.A. plantations.
2 Leiria E19xE40 – a controlled crossing of two plus parents selected in W.A. plantations.
3 Leiria MPDL – a mixture of seed from plus trees selected in Portugal.
4 Leiria routine – an unimproved bulk collection from Portugal (seed lot number S3697).
5 Landes 64445 – seed collected from plus tree 38.27 in France.
6 Landes 64435 – seed collected from plus tree 71.05 in France.
7 Corsica 3749 – seed collected from good trees in a stand at Vivario; altitude 800 m.
8 Corsica 3750 – seed collected from good trees in a stand at Porto Vecchia; altitude 900 m.
9 Corsica 3751 – seed collected from good trees in a stand at Zonza; altitude 700 m.
10 Corsica 3752 – seed collected from straight, vigorous trees in a stand at Chisoni; altitude 800 m.

Design – The trial was planted as a complete, randomized block design with 5 replications of the 10 seed sources. Square plots of 36 trees, at 2.4 m x 2.4 m spacing, were planted with tubed seedlings in June 1967.

Procedure – Seedlings received a spot application of 100 g of zinc superphosphate (zinc and copper additions) at planting and 500 kg of super plus 200 kg of urea broadcast per hectare in 1976.

The stand was thinned from the original

1680 stems ha^{-1} to 560 stems ha^{-1} (36 to 12 trees per plot) in September 1977.

Pruning of plots of Leirian origin was carried out in 1972 (to 2 m), 1977 (to 4 m) and 1979 (to 7 m). The other provenances were pruned later, always leaving at least 30 per cent of the green crown intact.

Measurement – Height was measured in 1971, 1975, 1977 and 1986. D.b.h. was measured at the last three dates.

In 1975, an assessment of form and branching was carried out using the categories in Table 2.

Results

Volume growth – Measurements up to age 19.5 years (Table 7) revealed a general superiority of the four Portuguese groups of which the routine was the poorest.

For stem diameter and total volume growth the full-sib (crossed) Leiria families and the half-sib (open pollinated) Leiria family (MPDL) were superior (.05 level) to the routine Portuguese imported seed batch which is significantly (.01 level) superior to the Landes and Corsican groups. These latter were not significantly different from each other in diameter but some variation existed between the better Landes family (64445) and the poorer Corsican groups (3749, 3752) in volume comparisons.

For height development to 19.5 years of age, all the Portuguese groups were significantly superior (.01 level). The Landes families were also significantly superior (.01 level) to the Corsican lots which showed some variation amongst themselves.

Form – Results of the stem form assessment at age 7.5 years (Table 7) reveal that for the percentage of ideal stems (those scored as 1 and 2) the Corsican provenances were markedly superior to the other two. One Landes family had superior form to the Portuguese routine and the other was equivalent to it.

Results for acceptable stems (categories 1, 2 and 3 which would involve little or no waste in processing owing to defect), were reasonably similar in ranking and emphasize the poor stem form often found in stands from commercial routine Portuguese seed. The proportion of stems of acceptable straightness in the three Leirian lots of selected origin was significantly higher than that of the routine lot.

Drought Resistance – In November 1977, prior to thinning, dead and severely damaged trees were distributed over all the treatment blocks but were concentrated within the Landes and Corsican provenance cells (Table 8).

Discussion

Trial XS12 is an efficient provenance test for evaluating differences between the major geographic groups considered for commercial plantation development in Western Australia. General results clearly confirmed observations of previous trials for growth and form characteristics. Knowledge of the extent of the variation between families within a provenance group has provided confidence in the interpretation of results for variation between groups.

Within this series of provenance trials, XS12 is particularly important in that it is the only trial with a good representation of the Corsican sources. They have consistently proved to be significantly straighter than other provenances.

There is a strong indication from trial results that selection and breeding within the Portuguese provenance would result in useful improvement in stem straightness. For example, the family E19xE40 approached the level of form in the Corsican race which has long been considered the best formed provenance (Hopkins 1960).

The years 1976 to 1977 were the driest on record in the region and resulted in considerable crown damage and pine deaths throughout the plantation. The trial provided an ideal field basis to assess the drought resistance of different provenances.

It was fortunate that the stands were suitably developed to clearly describe provenance response to the 1976–77 drought. This has not been demonstrated previously in mature trees. Clearly the Leirian provenance is the most drought-resistant of the provenances compared.

There was conjecture whether plus tree selection for form and vigour in the improvement program would be favourable to species' drought resistance. Results for controlled crosses in Table 8 indicate that they are at least as resistant as the parent population, which suggests that selection within the local breeding program will at least maintain the high drought resistance displayed by the race.

The Leirian families with significantly greater biomass (height and basal area) were superior in drought resistance (0.8 per cent mortality) to the Landes (9.7 per cent) and Corsican (10.1 per cent) groups. The latter groups were similar in sensitivity to drought with some variation between families. Results from other trials subject to the same drought (XS11, XS09, XR1) have supported these conclusions.

The results of this trial on a limestone soil are essentially similar to those obtained from trials on the deep grey Bassendean sands (McArthur and Bettenay 1960), thus indicating an adaptability of provenance to different soil types. The trial is also helpful in indicating the value of half-sib (MPDL) and full-sib (E19xE40, E5xE40) selections in improving commercial production of the species.

The advantage of the Portuguese provenance for volume production in Western Australia is obvious.

TABLE 7

Results for stem straightness at age 7.5 years and diameter, height and volume at age 19.5 years for trial XS12.

PROVENANCE GROUP	STAND AGE 7.5 YEARS STEM STRAIGHTNESS ACCEPTABLE RANK	%	IDEAL RANK	%	STAND AGE 19.5 YEARS VOLUME (m^3 ha^{-1}) RANK	MEAN	DIAMETER (cm) RANK	MEAN	HEIGHT (m) RANK	MEAN
Leiria E5xE40	5	67	8*	16	2	147.2	2	23.9	1	16.5
Leiria E19xE40	7	65	6*	23	1	149.4	1	24.1	2	16.3
Leiria MPDL	9*	60	7*	19	3*	138.6	3	23.7	3*	15.8
Leiria Routine	10*	51	9*	15	4*	118.9	4*	22.3	4*	15.4
Landes 64445	6	67	5	25	6	65.5	6	17.9	5	12.6
Landes 64435	8*	60	10*	13	10	49.1	10	17.0	6	12.2
Corsica 3749	1	72	3	32	9	49.6	9	17.5	9	10.6
Corsica 3750	3	70	2	32	8	53.4	8	17.6	7	11.1
Corsica 3751	2	72	1	33	5	61.5	5	18.1	8	11.0
Corsica 3752	4	68	4	30	7	53.7	7	17.6	10	10.3
LSD .05		9		8		11.3		1.2		0.6
LSD .01						15.1		1.7		0.8

* Not significantly different to the Routine control.

TABLE 8

Distribution of damage in trial XS12 resulting from the 1976–1977 drought. The trial was planted in 1967.

FAMILY AND PROVENANCE	TOTAL TREES PER FAMILY	NUMBER OF DEAD AND SEVERELY DAMAGED TREES BLOCK I	II	III	IV	V	TOTAL	DAMAGE %
E5xE40	180	0	0	0	0	0	0	0.0
E19xE40	180	0	0	1	0	0	1	0.6
MPDL	180	0	1	0	1	0	2	1.1
Routine	180	0	0	0	3	0	3	1.7
LEIRIA							6	0.8
64435	180	5	1	3	2	1	12	6.7
64445	180	3	7	2	2	9	23	12.8
LANDES							35	9.7
3749	180	10	1	1	6	5	23	12.8
3750	180	4	3	1	2	6	16	8.9
3751	180	0	1	2	5	2	10	5.6
3752	180	4	4	2	4	10	24	13.3
CORSICAN							73	10.1
Total	1800	26	18	12	25	33	114	6.3

Trial XS09 – Tunisian and Spanish Provenances at Gnangara

Establishment

There is no record of trials of seed sources from North Africa or Spain in early introductions of *P. pinaster* into Western Australia. Reports of comparisons in South Africa (Rycroft and Wicht 1947) gave little promise that the Moroccan could be of commercial advantage in South Africa. It was, however, desirable to test provenances from North Africa in Western Australia to provide future gene sources for the breeding program. In particular, the status of the drought resistance of the Portuguese improved race was questionable and African provenances might have had some advantage in this attribute. The availability of half-sib seed collected in Tunisia provided an opportunity to compare the characteristics of this North African source with Portuguese and Spanish sources in trials at Gnangara and Yanchep in 1966 and 1967.

Provenances – The following provenance groups were compared (Table 9):

1. Leirian full-sib – one seed lot, the standard cross E40xE2 used as a tester in the improvement program.
2. Leirian half-sib – eight separate seed lots from trees E104, E110, E115, E121, E131, E152, E173 and E181 selected as plus trees in the forest of Leiria.
3. Leirian Routine – one commercial seed lot imported from the forest of Leiria.
4. North Spain – one pooled seed lot collected from 5 trees in a plantation at Barreiros by Perry (Perry and Hopkins 1967) on the north coast of Spain. The trees were of good form and vigour with dense, dark green crowns.
5. West Spain – one pooled seed lot collected by Perry near La Toja west of Pontevedra on the west coast of Spain, from about 20 fast growing trees of good form.
6. Tunisian half-sib – 24 half-sib seed lots from plus trees at Ain Baccouch in north-west Tunisia.

Trial Design – Ten-tree line plots with 8 replications were used in randomized blocks.

Procedure – Plants were raised in tubes and planted out with superphosphate fertilizer spot application in June 1966. The initial spacing of 2150 stems ha^{-1} was thinned to 1080 stems ha^{-1} (10 plants reduced to 5 in each line plot) in 1971, to 430 stems ha^{-1} (5 to 2 in each line plot) in 1977 and to 215 stems ha^{-1} (2 to 1 in each line plot) in September 1980.

Superphosphate was broadcast at the rate of 500 kg ha^{-1} in October 1972 and 500 kg ha^{-1} of Agras (NP) fertilizer was broadcast in September 1981.

Pruning was carried out in 1971 (to 2m), 1975 (to 4m) and 1980 (to 7m).

Measurement – Heights were measured in June 1970 (age 4 years) and both heights and diameters were measured in December 1976 (age 10.4 years).

Results

Height and diameter means from the 1976 measurement (Table 9) show a clear separation of the Atlantic and Tunisian provenance groups. All Tunisian families were significantly less than the Spanish and Leirian provenances in height growth and significantly inferior (.01 level) in diameter growth, except for the North Spain and E138 and E173 Leirian batches. Generally the Portuguese and Tunisian families showed uniform and continuous variation within groups.

Only four of the Atlantic coast families (E152, E40xE2, E131, E104) grew significantly faster (.05 level) than the routine source for height growth while none, within the Atlantic group, differed significantly from this control for diameter.

Discussion

The mean heights and diameters of the Spanish provenances and the commercial Portuguese routine source did not differ significantly from each other. Field descriptions (Perry and Hopkins 1967) had indicated phenotypic similarity between these groups.

Seedlings of the Tunisian provenance were distinctively different in appearance from those of other *Pinus pinaster* provenances in the nursery. The bud has a whitish edge to the scale that is like that of *P. canariensis* in the nursery stage. The experimental site is adjacent to a swampy area and in the early stages of the trial all the Tunisian trees were covered with the woolly aphid (*Pineus pini*). Only occasional trees of Portuguese origin were affected by the insect.

The Tunisian trees were the most precocious in flowering of all provenances tested in Western Australia. Abundant pollen and cone development was apparent within four years of planting.

Stem form of the Tunisian families was inferior to that of the better Leirian groups but this was not quantitatively assessed (see Trial XR1 for an assessment of this trait).

No significant mortalities occurred in any family in trial XS09 during the 1976 drought. Some adjacent trials were severely affected and good survival in trial XS09 could have been owing to its wetter locality and its well thinned condition. The comparison for drought resistance was better made in trial XR1 which was established on a very drought-prone site.

Trial XR1 – Strip Comparisons

Establishment

Trial XR1 differs from all other provenance comparisons in this series in that it does not follow a normal statistically controlled design. The objectives were to:

1 Establish on a similar site a wide range of provenances, some with limited plant numbers. The large numbers of provenances available for

TABLE 9

Mean height and diameter of Portuguese and Spanish provenances and half-sib Tunisian families in trial XS09 at age 10 years.

RANK	HEIGHT (m)		DIAMETER OVER BARK (cm)	
	FAMILY	MEAN	FAMILY	MEAN
1	P E152	8.7	P E40xE2	13.5*
2	P E40xE2	8.7	P E131	13.3*
3	P E131	8.5	P E152	13.1*
4	P E104	8.5	P E104	13.1*
5	P E110	8.3*	P E110	13.1*
6	P E118	8.1*	P E181	13.0*
7	P E145	8.1*	P E118	12.9*
8	P E121	8.1*	P E115	12.5*
9	P E115	8.1*	P E145	12.5*
10	Spain West	8.1*	P E121	12.4*
11	P E181	7.8*	P Routine	12.3*
12	P E156	7.8*	Spain West	12.1*
13	P Routine	7.8*	P E156	11.9*
14	P E138	7.7*	P E173	11.9*
15	P E173	7.7*	P E138	11.7*
16	Spain North	7.6*	Spain North	11.3*
17	T 3539	6.2	T 3539	10.7
18	T 3524	6.1	T 3543	10.2
19	T 3529	5.9	T 3524	10.1
20	T 3547	5.8	T 3528	10.0
21	T 3528	5.7	T 3527	10.0
22	T 3541	5.6	T 3529	10.0
23	T 3532	5.6	T 3541	9.9
24	T 3527	5.6	T 3547	9.7
25	T 3535	5.6	T 3545	9.6
26	T 3537	5.5	T 3530	9.6
27	T 3533	5.5	T 3535	9.5
28	T 3526	5.5	T 3544	9.5
29	T 3545	5.5	T 3534	9.4
30	T 3543	5.4	T 3546	9.4
31	T 3530	5.4	T 3532	9.3
32	T 3546	5.4	T 3537	9.2
33	T 3534	5.3	T 3526	9.2
34	T 3544	5.3	T 3533	9.1
35	T 3525	5.2	T 3538	9.1
36	T 3542	5.1	T 3525	8.7
37	T 3540	5.1	T 3531	8.6
38	T 3538	5.1	T 3542	8.6
39	T 3531	5.0	T 3540	8.3
40	T 3536	4.8	T 3536	8.1
	LSD .05 =	0.62	LSD .05 =	1.10
	LSD .01 =	0.81	LSD .01 =	1.45

P Portuguese T Tunisian families.

* Not significantly different (.05 level) to the Routine Control.

comparison, the varying importance of the provenance groups to the local program and the small numbers of seeds available in some groups either precluded replication within a standard experimental design or did not warrant the work involved in establishing and measuring such a trial.

2 Use an interplanted control seed source as a standard or covariant on which to rate the performance of each provenance and to overcome problems caused by site variation within the test area.

3 Evaluate Spanish, Italian and Tunisian provenances under drought-prone conditions and on the yellow limestone sands of the Spearwood Dune Series (McArthur and Bettenay 1960).

Provenances – Provenances tested included:

1 Routine – imported Portuguese seed (S3352) used as the control.

2 Leiria S2 – a full-sib family with plus parents (E40xE2), used as a standard in all progeny trials.

3 PDL4 – half-sib seed from a plus tree selected in Portugal (E104).

4 Portugal – a batch of seed collected from an isolated stand near Lamego in north Portugal.

5 Landes 1 and 2 – two half-sib families from plus trees in the Landes forest (S2860, S2865).

6 Tunisia 1 to 6 – six batches of seed mixed from eighteen half-sib collections from Tunisian plus trees.

7 Lucca – an Italian provenance from Lucca in Tuscany (S2855).

8 Italy – a general Italian provenance (S2864).

9 Spain – seed collected at Barreiros on the north-west coast of Spain.

Design – The trial was established in a rectangular block with 130 rows of trees aligned in a north-south direction. Each row was 120 m long and included approximately 60 trees at 1.8 m spacing. Spacing between rows was 2.4 m (i.e. a stocking of 2243 stems ha^{-1}). Each provenance or family (or mixture of families in the case of some Tunisian groups) was planted in a strip of four rows with four rows of the routine Portuguese stock on either side as a control. Sufficient stock was available for the Spanish and Leirian S2 seed lots to be planted twice to provide some replication within the trial. The outer three trees at the end of each row were regarded as a buffer and omitted from measurement.

The trial was established in two sections and only the section in Compartment 48A is considered in this report.

Procedure – The trial was planted at Yanchep in 1966 on yellow coastal sands. The site is flat with a slight increase in elevation from west to east.

The control and most other stock was open rooted and planted by machine; the tubed stock (Leiria S2) was planted by hand.

Trees were low pruned in November 1976 and thinned to approximately 450 stems ha^{-1} in May 1980.

Measurement – The trial was evaluated in 1979 by students from the Western Australian Institute of Technology. Fifteen trees in each of the two inner rows of each four-row bay were measured to allow a mean of 30 trees of each provenance to be compared by 't' tests with that of the adjacent controls. Form was subjectively assessed on the basis of the standards presented in Table 2.

Results

Results are presented in Tables 10 and 11. In Figure 4 the impact of topography on site index is depicted by the dotted line for height of the routine Leiria control in the height graphs.

Height and Diameter – At age 13 years, the full-sib and half-sib Leiria (S2, PDL4) and one of the two North Spain plantings were significantly better in height growth than the control (Table 10). With the exception of the other North Spain lot and Landes 1 (S2860), all other provenances were significantly poorer in height growth than the adjacent Portuguese control.

Trees of the Spanish source located on the higher site quality end of the trial were significantly smaller in diameter than the control, but the other Spanish samples and all Portuguese provenances equalled or exceeded the control. Three Tunisian groups, Landes 2 (S2865) and both Italian provenances were significantly inferior in diameter growth.

Form – The percentage of trees with above average bole straightness in Figure 4 varied from 8 to 63 for the control (Table 11) over the range of the trial. Similarly, the same Spanish provenance at each end of the trial varied from 14 to 56 per cent. There is no reason for such differences to be associated with site variation and the trend is not in accord with variations measured in site index. This wide variation, present in the assessment procedure for this attribute, makes the data most suspect and difficult to interpret.

Variation in results in the control provenance for other form characteristics restricts interpretation. It should be noted however, that for form characteristics, the adjacent full-sib groups S2 and the half-sib PDL have good agreement. Most differences in the trial can thus be associated with actual variation within the provenance groups and not necessarily with site or measurement effects.

The results clearly demonstrate the flatter branch angle in the Tunisian and Italian trees as distinct from the typical high angled branching pattern present in all Atlantic provenances.

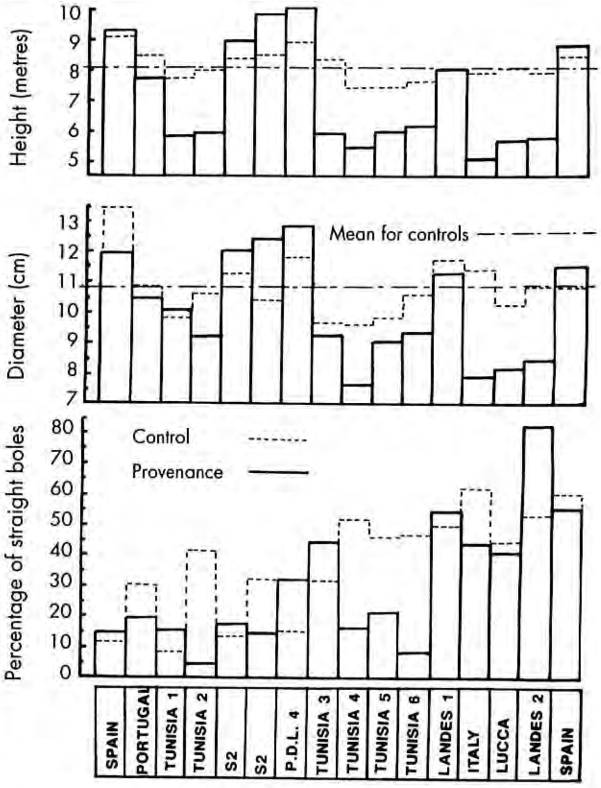

Figure 4. Variation in height, diameter and bole straightness for the provenances in trial XR1 at Yanchep. The general mean for all routine (Leiria) control plots and the actual control means for each comparison are superimposed as dashed lines. Plants were 13 years old at measurement.

Discussion

This field trial demonstrates the importance of replication in interpretation and validity of results. By itself it has little merit for provenance evaluation other than as a reconnaissance procedure. However, results for height and diameter growth are in accord with those of other trials and it has extended the findings on the grey sands at Gnangara to the drought-prone limestone sands at Yanchep (trial XS09).

The results show that the Atlantic group (Portuguese, Landes and north-coastal Spain) performed best in height and diameter growth and the Tunisian and Italian groups were inferior in these respects.

The Spanish and Portuguese groups did not differ in stem straightness (Table 11) from the control. This performance is as expected from descriptions of the provenance in the field (Perry and Hopkins 1967). The Landes group was as good or better than the control in straightness and the Tunisian and Italian groups were generally inferior.

No useful comment can be made for results on the frequency of trees without forks, ramicorns or damaged leaders (Table 11). Most provenances are as good as, or better than, the imported Portuguese seed batch. Forking and ramicorns have long been recognized as major form defects in imported Portuguese stock.

Results for branch angle shown in Table 11 suggest that the Tunisian and Italian provenances have a higher proportion of flat (low angle) branching. This supports field observations in trials 3/65 and XS09 and the general expectation of Mediterranean races. Spanish and Landes groups have higher angled branching, similar to the Portuguese group and a characteristic of the Atlantic race.

Trial results for branch thickness cannot be interpreted to show any real advantage over the control (see also trials YS51, YS52, YS53).

This preliminary analysis of the trial suggests that excessive variation is associated with inconsistency of measurement and an inadequate sample size in each plant group. Data do not warrant covariant analysis

TABLE 10

Mean survival, height and diameter of unreplicated strip plantings of various provenances at age 13 years for trial XR1. Significance is at the 0.05 level and represents differences between the provenance and the adjacent control, evaluated by 't' tests. The Routine Leirian seed batch was used as the control.

PROVENANCE	SURVIVAL (%)		MEAN HEIGHT (m)			MEAN DIAMETER (cm)		
	PROV.	CONTROL	PROV.	CONTROL	SIGNIF.	PROV.	CONTROL	SIGNIF.
Spain (Barreiros)	90	100	9.2	9.0	NS	11.9	13.3	*
Spain (Barreiros)	83	97	8.8	8.3	*	11.5	10.8	NS
Tunisia 1	90	90	5.9	7.7	*	10.1	9.7	NS
Tunisia 2	90	90	5.9	7.9	*	9.1	10.5	*
Tunisia 3	87	93	5.8	8.3	*	9.1	9.6	NS
Tunisia 4	87	93	5.4	7.3	*	7.6	9.5	*
Tunisia 5	100	97	5.9	7.3	*	8.9	9.8	NS
Tunisia 6	80	100	6.0	7.5	*	9.2	10.5	*
Landes S2860	97	93	7.9	7.9	NS	11.2	11.7	NS
Landes S2865	80	87	5.7	7.8	*	8.4	10.8	*
Italian	53	90	5.0	7.8	*	7.8	11.4	*
Lucca	97	97	5.6	7.9	*	8.1	10.2	*
Portugal (Lamego)	90	93	7.7	8.4	*	10.3	10.8	NS
Leiria S2	97	80	9.0	8.3	*	12.0	11.2	NS
Leiria S2	97	97	9.8	8.4	*	12.3	10.3	*
Leiria PDL 4	93	83	9.9	8.8	*	12.8	11.7	NS

Tunisia 1	S3543	
Tunisia 2	S3524	
Tunisia 3	S3528,29,35,46	Mixtures of W.A. serial numbers
Tunisia 4	S3526,30,33,40	Mixtures of W.A. serial numbers
Tunisia 5	S3525,32,36,47	Mixtures of W.A. serial numbers
Tunisia 6	S3537,39,42,44	Mixtures of W.A. serial numbers

Prov. – Provenance mean
Control – Control mean

unless a more comprehensive measurement is carried out. This is not expected as indications of provenance performances in the trial are satisfactorily explained in conjunction with associated trials.

Form assessment is a subjective procedure and consistent results can only be obtained using experienced and reliable assessment crews and allowance must be made for inaccuracy owing to inexperience of the students measuring the trial. It is not practical, however, to fully test all provenances or progeny groups which may have merit to a local program and as a broad based screening medium the trial procedure may be useful. It is well backed by trial XS09, on the sands at Gnangara, to provide for a satisfactory evaluation of the Tunisian and Spanish groups.

If the design must be employed in future, several obvious improvements are worth considering:

1 A full-sib or half-sib family should be used as the control to reduce the excessive variation inherent in non-selected routine seed collections.
2 If it is not possible to use a full-sib family as a control measurement units of the order of 50 trees should be employed to improve the sample of each provenance.
3 Several provenances should be duplicated to gauge the extent of variation in comparisons.
4 Form assessment should be kept simple and restricted to experienced assessors.

Drought Deaths – During the 1976 drought, scattered deaths occurred within the trial. Assessment of survival numbers (Table 10) revealed that the Italian and one Tunisian batch fared worse than the routine control. In general, however, survival of all other provenance groups, in particular the full-sib and half-sib Leirian selections, is considered most satisfactory under the conditions.

TABLE 11

Comparisons of stem form in unreplicated plantings of various provenances in trial XR1 at age 13 years. The Routine Leirian seed batch was used as the control.

PROVENANCE	PERCENTAGE OF ABOVE-AVERAGE STEMS							
	STRAIGHTNESS		BRANCH THICKNESS		BRANCH ANGLE		NOT FORKED	
	PROV.	CONTROL	PROV.	CONTROL	PROV.	CONTROL	PROV.	CONTROL
Spain (Barreiros)	14	11	7	14	7	21	69	43
Spain (Barreiros)	56	61	4	4	0	7	100	75
Tunisia 1	15	8	7	4	26	33	78	71
Tunisia 2	4	41	11	15	41	30	52	78
Tunisia 3	44	32	24	14	28	7	92	61
Tunisia 4	16	52	24	22	20	4	96	93
Tunisia 5	21	46	28	14	62	0	97	100
Tunisia 6	8	47	0	17	50	3	100	100
Landes 1(S2860)	55	50	10	0	7	4	97	89
Landes 2(S2865)	83	54	4	4	0	15	96	81
Italian	44	63	0	7	31	7	100	85
Lucca	41	45	3	10	34	21	90	86
Portugal (Lamego)	19	30	5	11	5	15	86	59
Leiria S2	17	13	3	0	0	25	76	54
Leiria S2	14	32	0	7	0	0	72	86
Leiria PDL 4	32	14	11	0	0	0	68	68

Prov. – Provenance mean
Control – Control mean

Landes Half-sib Families

A further group of trials (XS11, YS08, YS09, YS10) within the early improvement program incorporated half-sib families of plus trees selected in forests of the French Landes region. These were compared with routine Leirian imported seed, full-sib Leirian crosses from local selections and half-sib Leirian families from plus trees in Portugal.

At the time, plus tree selection and evaluation accounted for a major part of the time spent on tree breeding. Interest in French half-sib material was high as some West Australian foresters still favoured the Landes seed and therefore it required thorough testing.

Trial XS11 was established at Gnangara in 1967 and included 14 Landes half-sib families. Trials YS08, YS09 and YS10 contained 4, 9 and 10 Landes families respectively, of which at least four are common to two sites. They have the routine, half-sib Portuguese and at least 9 full-sib Leirian crosses in common and represent a wide range of soils at Gnangara, Yanchep and Mundaring.

Trial XS11 – Comparisons of Leirian and Landes Families at Gnangara

Establishment

Provenances – Trial XS11 incorporates a routine imported Leirian seed batch (S3697), a mixture of half-sib seeds from plus phenotypes selected in Portugal (MPDL), 4 full-sib crosses from Portuguese plus trees selected in local plantations and 14 half-sib families from plus trees selected in French Landes forests.

Design – The families were planted out in 10-tree line plots with 10 replications in a randomized block design.

Procedure – The trial was established in June 1967, with tubed stock, in Clover Block, Gnangara plantation. Planting was at 3 m x 3 m spacing (1080 stems ha^{-1}). In August 1977, the trial was thinned to 540 stems ha^{-1} (10 trees to 5 per plot) and in September 1980 the stand was further reduced from 5 trees to 2 per plot.

Fertilizer was added as a spot application of 60 g of superphosphate per seedling at time of planting and 500 kg ha^{-1} of superphosphate was broadcast on the trial in September 1972. In 1976 a further 500 kg ha^{-1} of superphosphate plus 200 kg ha^{-1} of urea was broadcast.

The trial was pruned progressively to 7 m height.

Measurement – Heights were measured and survivors counted in January 1971. Height and diameters were measured in December 1976. In 1977 a drought damage assessment was made prior to thinning.

Results

Results for the measurements and analysis are set out in Table 12.

Height and Diameter – At 3.5 years of age superior height growth was evident in the Portuguese families. By age 9.5 years this superiority was significantly (.01 level) taller and of greater diameter than any of the Landes families. At this stage the MPDL was similar to the Portuguese routine batch in both height and diameter. All crosses from local selections were significantly better than the imported routine seed batch.

The Landes families varied significantly among themselves in both height and diameter.

Drought Damage – Drought damage was well distributed over the entire trial area. Damage was greatest in the Landes families (Table 12) and was reasonably high for the Portuguese routine. It was negligible for the full-sib crosses and the half-sib Portuguese selections.

Discussion

Results from this trial containing half-sib families of a number of the best plus trees selected in the French breeding program show that their growth was significantly inferior to the Portuguese control and improved Leirian families under Western Australian conditions. This is supported by other performances of Landes half-sib groups in trial XS12 (Table 7) on limestone soils, and trials YS08, YS09, YS10.

The clear and consistent results for resistance to drought damage in this and other trials (XS12, YS09) establishes the superiority of the Leirian provenance in drought resistance. The full-sib crosses resulting from selections among acclimatized plus trees in Western Australia have retained and improved on the drought resistance of the imported routine control.

The significance of the superior drought resistance of the Leirian race can be appreciated better when it is realized that at the onset of the drought in 1976-77, the Portuguese trees carried 150 per cent more stem volume and 28 per cent more basal area and hence had a far greater water requirement than trees of the Landes provenance. These results are confirmed by details of mortalities in trial YS09 (See Table 16) to be discussed later.

Variation within the Landes half-sib group and the highly significant differences obtained by acclimatization and selection in the Portuguese group (Table 12) reveal the scope for provenance improvement, to meet specific conditions. The data also indicate the degree of variation that may be experienced between different provenances within a major geographic group and with different standards or procedures for seed collection. Obviously there is need for replication in provenances and a defined basis for seed collection, if one is to be confident that trials clearly demonstrate the relative potentials of the different geographic groups.

Trial YS08 – Comparisons of Leiria and Landes Families at Gnangara

Establishment

Provenances – Trial YS08 compared 20 seed lots covering the following provenance groups:

1. Leiria full-sib – 14 full-sib families from controlled crosses of plus trees selected in Western Australia. One of these crosses was a selfing (E40xE40).
2. Routine – a commercial seed batch (S3697) imported from Portugal, reputedly from the forest of Leiria, used as the control.
3. Leirian half-sib – MPDL, a mixture of half-sib seed lots from plus trees selected in Portugal.
4. Landes cross – LSMA, a mixture of seed from crossings between Landes and Leiria plus trees.
5. Landes half-sib – three separate seed lots from plus trees selected in the Landes forests in France (L60252, L60253 and L1103).

Design – The families or provenances were planted out in 10-tree line plots with 10 replications in a randomized block design.

Procedure – The trial was established from tubed stock in June 1967 on grey sands in Clover Block, Gnangara Plantation. Planting was at 3 m x 3 m spacing. Thinning in August 1977 reduced the stocking from 1080 to 540 stems ha^{-1} (from 10 to 5 trees per plot). The stand was further reduced in October 1980 from 5 trees to 2 trees per plot.

Fertilizer was added as a spot application of 60 g of superphosphate per seedling at time of planting and 500 kg ha^{-1} of superphosphate was broadcast in September 1972. In August 1978, 500 kg ha^{-1} of Agras (NP) fertilizer was broadcast.

Lupins were sown on the trial area in 1981 with dressings of 200 to 300 kg ha^{-1} of superphosphate in 1981 and 1983.

The trial was pruned in stages to 7.5 m height.

Measurement – Heights were measured in January 1971, April 1975 and August 1977. Diameters were measured in April 1975, August 1977 and March 1980. A form assessment for stem straightness and branch thickness was carried out in October 1975.

Results

Height and Diameter – Results for height and diameter are listed in Table 13. Two of the three Landes families, the Portuguese mixed half-sib group (MPDL) and 4 full-sib families were significantly poorer in height growth than the routine control at age 3.5

TABLE 12

Results for growth and drought survival for full-sib Leirian families and half-sib Landes families in trial XS11 at Gnangara up to age 10 years.

FAMILY	AGE 3.5 YEARS HEIGHT		AGE 9.5 YEARS HEIGHT		DIAMETER		AGE 10 YEARS DROUGHT DEATHS
	MEAN (m)	RANK	MEAN (m)	RANK	MEAN (cm)	RANK	%
E5xE40	2.40	1	7.3	1	10.6	3	2
E45xE40	2.10	3	7.1	2	10.8	1	0
E40xE2	2.01	6	7.1	3	10.8	2	0
E19xE40	2.16	2	7.0	4	10.6	4	0
(E)MPDL	2.06	4	6.5*	5	9.7*	6	2
(E)Routine	2.05	5	6.4*	6	9.8*	5	5
L64391	1.92	9	5.9	7	9.1*	8	1
L64437	1.98	8	5.9	8	9.2*	7	3
L62354	1.87	12	5.9	9	8.5	13	4
L622368	1.99	7	5.8	10	8.7	10	20
L64417	1.87	11	5.7	11	8.6	12	14
L62366	1.82	14	5.7	12	8.5	14	5
L62365	1.74	19	5.7	13	8.7	11	1
L64432	1.80	16	5.5	14	8.4	15	2
L64430	1.85	13	5.5	15	8.0	18	13
L62355	1.81	15	5.5	16	8.7	9	11
L62348	1.78	18	5.5	17	7.9	19	2
L64434	1.88	10	5.4	18	7.9	20	10
L64422	1.79	17	5.3	19	8.0	17	12
L62362	1.66	20	5.2	20	8.0	16	12
LSD .05	—		0.34		0.70		—
LSD .01	—		0.44		0.92		—

Family designation commencing E – Portuguese.
Family designation commencing L – Landes.

* Not significantly (.05 level) different to Routine.

years. By age 7.5 years all Landes half-sib groups and the Leiria selfing (E40xE40) were significantly inferior in height and diameter to all other Portuguese families and the Landes by Leiria cross (LSMA). This was also the position with respect to diameter at 13 years of age.

Tree Form – Means obtained for the form assessment at age 8.5 years are presented in Table 14. These refer to the percentage of trees scored in the two better classes (out of 3) for each trait (See Table 2). Percentages are left in the arcsin transformation to allow comparison of means by the least significant difference (LSD) values.

Branch thickness comparisons in Table 14 at age 8.5 years reveal that the Leirian routine, the Landes and two Leirian full-sib groups (E15xE2, E15xE40) contained most trees with heavy branching and were similar in this respect. The Portuguese half-sib (MPDL) and remaining Leirian full-sib crosses were significantly superior in fine branching.

Results for branch angle show little variation in the proportion of flatter branching between families from both Portugal and France. Two full-sib families (E5xE40, E33xE40) show improvement through selection while another family (E28xE2) was inferior to the routine source.

The provenances poorest for stem straightness were the Landes, the Portuguese routine and three full-sib Leiria crosses (E40xE2, E5xE40, E28xE2). Variation within the Leiria pedigree group ranged from 41 to 8 per cent trees with acceptable stem straightness. Plus tree selection in Portugal (MPDL) and local plantations provided superior stem straightness coupled with superior vigour. The good tree form of the selfed family (E40xE40), in Table 14, indicates that selfing may offer a useful pathway to form improvement in the Leirian population.

TABLE 13
Comparison of Portuguese and Landes families for height and diameter growth with age in trial YS08.

FAMILY	AGE 3.5 YEARS HEIGHT (m) MEAN	RANK	AGE 7.5 YEARS HEIGHT (m) MEAN	RANK	DIAMETER (cm) MEAN	RANK	AGE 13.0 YEARS DIAMETER (cm) MEAN	RANK
E5xE40	2.79	2	7.2	2	10.9*	6	17.3*	6
E14xE40	2.43	14	6.7*	12	10.6*	12	17.0*	7
E15xE50	2.79	1	7.0	6	11.7	1	18.7	2
E19xE40	2.54*	8	6.8*	10	10.7*	10	16.6*	14
E28xE40	2.57*	6	6.8*	11	10.5*	13	16.5*	15
E33xE40	2.46*	12	7.0	5	10.6*	11	16.7*	10
E40xE40	2.26	19	6.1	17	9.1	18	14.6	17
E41xE40	2.71*	3	7.0	4	10.9*	5	16.7*	12
E45xE40	2.67*	4	6.8*	9	10.7*	8	17.0*	8
E47xE40	2.35	17	6.7*	13	10.3*	16	16.8*	9
E15xE2	2.54*	7	6.9	7	11.5	2	19.0	1
E28xE2	2.45*	13	6.9	8	10.9*	7	17.7	5
E33xE2	2.40	16	7.2	1	11.2	4	18.1	4
E40xE2	2.49*	10	7.1	3	11.4	3	18.6	3
MPDL	2.42	15	6.6*	14	10.3*	15	16.7*	11
Routine	2.60*	5	6.5*	16	10.7*	9	16.3*	16
LSMA	2.53*	9	6.6*	15	10.5	14	16.6*	13
L60251	2.47*	11	6.1	18	9.5	17	14.0	18
L60253	2.30	19	5.6	20	8.6	20	12.7	20
L61103	2.20	20	5.7	19	8.9	19	13.4	19
LSD .05	0.16		0.30		0.76		1.10	

The Landes are designated by L.
* Not significantly different (.05 level) to the Routine control.

Discussion

The trial results support other local studies in demonstrating the superiority in height and diameter growth of stands from Leirian seed over those from the Landes region.

Within the Leirian group the only family significantly poorer for growth than the routine control was the selfing E40xE40 (Table 13). Generally the families resulting from crosses between plus trees were significantly better than the routine control.

The Landes by Leiria cross (LSMA) is interesting in that its growth was intermediate between that of Landes and Leirian families. This result was confirmed from other trials (YS51, YS52, YS53) and reports of early selection work in France by Alazard (1982).

The superiority of vigour of Leirian families has already been demonstrated in other trials. The major value of the current trial is in the further definition of characteristics of stem form and branching between the Leirian and Landes provenances. No differences could be detected for percentage of fine branches between the routine Portuguese, LSMA and two of the three Landes half-sib families. This is contrary to similarities between the provenances demonstrated in trial 3/65 (Table 6).

It was not possible to distinguish between the Landes and most of the Leirian families on the basis of branch angle. In trial 3/65 (Table 6) the Landes provenance contained a higher percentage of trees with favourable branch angle. There are reasons to suspect, however, that the seed lot used to represent the Landes area in that trial had greater affinity with the Corsican race than with the normal Landes population. Evidence for future improvement within the Portuguese group is shown in Table 14 where the proportion of trees with acceptable branching in E5xE40 and E33xE40 is significantly (.01 level) superior to the rest. Lack of attention to this factor in selection could worsen the situation as demonstrated by the cross E28xE2 which is significantly (.01 level) poorer in branching than all other families in the trial. Parent E28 was culled from seed orchards as a result of early test results.

Stem straightness was similar between the Landes families and the imported Portuguese control. This was

TABLE 14

Comparison of Portuguese and Landes provenances for branch size, branch angle and stem straightness in trial YS08 at 8.5 years of age. Means are for percentage of acceptable stems.

	PERCENTAGE OF ACCEPTABLE TREES					
FAMILY	BRANCH THICKNESS		BRANCH ANGLE		STEM STRAIGHTNESS	
	MEAN	RANK	MEAN	RANK	MEAN	RANK
E5xE40	76.5	1	88.2	1	20.7*	13
E14xE40	71.7	6	76.2*	5	31.2	4
E15xE50	48.0*	16	70.5*	13	8.1*	17
E19xE40	64.9	10	75.6*	6	22.8	10
E28xE40	72.6	5	61.5*	18	25.8	8
E33xE40	73.2	4	85.5	2	41.4	1
E40xE40	75.0	2	78.0*	4	34.5	2
E41xE40	66.3	8	72.9*	11	29.1	7
E45xE40	74.1	3	73.8*	9	30.6	6
E47xE40	64.2	11	66.0*	16	32.4	3
E15xE2	52.8*	14	67.8*	14	22.8	11
E28xE2	60.9	12	35.4	20	22.2 *	12
E33xE2	66.3	9	73.8*	8	30.6	5
E40xE2	71.4	7	78.6*	3	19.5*	14
MPDL	58.8	13	73.5*	10	24.3	9
Routine	43.2*	17	66.9*	15	10.5*	16
LSMA	52.5*	15	75.0*	7	19.5*	15
L60251	39.6*	19	63.6*	17	1.8*	20
L60253	30.9	20	55.7*	19	4.5*	19
L61103	43.2*	18	71.1*	12	8.1*	18
LSD .05	11.0		12.3		9.6	
LSD .01	14.0		16.0		12.7	

The Landes are designated by L.

* Not significantly different (.05 level) to the Routine control.

also the case in one of two Landes families in trial XS12 (Table 7) but the other family and the seed lot used in trial 3/65 (Table 6) had better straightness than the unimproved Leirian plants.

The improved straightness of the top 11 Leirian crosses in the current trial (Table 14) and the excellent performance of the selfing E40xE40 in this respect, indicates that selection within the provenance is effective in improving this characteristic. Selfing may be of future assistance in this area and an extensive selfing program was carried out for many of the initial local plus tree selections.

Two features of these results are the favourable branch size shown by the less vigorous selfing E40xE40 (Table 14) and the relatively poor form displayed by E15xE2 and E15xE40. The plus parent E15 was subsequently culled from the breeding program on the basis of consistent poor performance in branching and the use of E2 was restricted on the basis of poor form and early height growth.

Trials YS09 and YS10 – Comparisons of Leirian and Landes Families at Yanchep and Mundaring

Establishment

Trials YS09 and YS10 are similar to YS08 and were designed to evaluate a wider range of Landes half-sib families on two further, very different soil types. YS09 is located on the more fertile limestone soils at Yanchep where drought is more significant. YS10 is planted on good quality red loam soils at Mundaring some 60 km east of Perth in the Darling Range. Here, superior soil, temperature and rainfall conditions favour the growth of *Pinus radiata*, and *P. pinaster* cannot compete as a commercial alternative.

Provenances – Trial YS09 includes 11 Leirian (9 full-sib, 1 routine, 1 half-sib) groups and 9 Landes (half-sib) groups (Table 15). YS10 has 10 Leirian and 11 Landes groups (Table 16).

Design – Trial YS09 is a randomized block experiment with 10 replications of 10-tree line plots.

YS09 was fertilized with 500 $kg\,ha^{-1}$ of super-copper-zinc fertilizer in October 1972 and 500 $kg\,ha^{-1}$ Agras (NP) in September 1978. Thinning was to 5 trees per plot in August 1977 and to 2 trees per plot in October 1980.

Pruning was completed to height 7.5 m by March 1981.

YS10 is a randomized block experiment with 20 replications of 5-tree line plots. Smaller plots were used on account of the greater site variation present.

YS10 was fertilized with 500 $kg\,ha^{-1}$ of super-copper-zinc fertilizer in September 1973 and 400 $kg\,ha^{-1}$ of super-copper-molybdenum-zinc with 20 $kg\,ha^{-1}$ of Seaton Park clover in May 1982. Thinning was from 5 to 2 trees per plot (430 stems ha^{-1}) in November 1977 and from 2 to 1 trees per plot (215 stems ha^{-1}) in March 1982.

Pruning was completed to 4.5 m in March 1978.

Measurement – Trial YS09 was measured in January 1971 for height, in April 1975 and August 1977 for height and diameter and in March 1980 for diameter only. In October 1975 a form assessment for stem straightness, branch angle and branch thickness was undertaken on all Portuguese families and one Landes family.

Trial YS10 was measured in 1971 for height and in February 1976, October 1977 and March 1981 for diameter.

Results

Height and Diameter – In both trials the growth of the Landes families (Tables 15 and 16) was inferior to that of the Portuguese groups. This confirmed other results for the complete separation of the two provenance (racial) groups for growth characteristics, over a wide range of soil conditions, in Western Australia.

TABLE 15

Results for growth and straightness comparing Leirian and Landes (L) provenances in trial YS09 planted in 1967 at Yanchep.

RANK	AGE 3.6 YEARS HEIGHT (m)		AGE 7.5 YEARS # STRAIGHTNESS (TRANSFORMED)		AGE 10 YEARS VOLUME (m^3)		AGE 12.7 YEARS DIAMETER (cm)	
	FAMILY	MEAN	FAMILY	% 1,2	FAMILY	MEAN	FAMILY	MEAN
1	E5xE40	3.28	E47xE40	41.1	E15xE40	.020	E15xE40	19.0
2	E19xE40	3.26	E40xE2	37.5	E19xE40	.018	E40xE2	18.7
3	E15xE40	3.22	E41xE40	35.4	E45xE40	.018	E19xE40	18.2
4	E41xE40	3.17	E45xE40	34.5	E5xE40	.018	E41xE40	17.9
5	E45xE40	3.07*	E28xE40	31.2	E40xE2	.018	E45xE40	17.8
6	E28xE40	3.04*	E28xE2	28.8	E41xE40	.017	E47xE40	17.7
7	E40xE2	3.04*	E5xE40	28.2	E47xE40	.016*	E5xE40	17.7
8	Routine	2.99*	E19xE40	24.3	E28xE40	.015*	LSMA	17.6
9	MPDL	2.97*	E15xE40	19.2	E28xE2	.015*	E28xE2	17.3*
10	E47xE40	2.96*	L60252	7.2*	Routine	.015*	E28xE40	17.0*
11	E28xE2	2.93*	Routine	5.4*	LSMA	.014*	Routine	16.7*
12	LSMA	2.88*			MPDL	.014*	MPDL	16.5*
13	L61238	2.86*			L61104	.012	L61104	15.2
14	L61240	2.77			L61238	.011	L61103	15.0
15	L61104	2.74			L61240	.010	L61238	15.0
16	L60252	2.70			L60252	.010	L61105	14.7
17	L61105	2.59			L61105	.010	L61240	14.7
18	L60253	2.52			L61103	.009	L62065	14.3
19	L62065	2.44			L60253	.009	L60252	14.2
20	L61103	2.41			L62065	.009	L60253	14.0
LSD .05		0.13		9.6		.001		0.8
LSD .01		0.17		12.7		—		1.1

* Not significantly (.05 level) different to the Routine.

E – full-sib Portuguese plus families. L – Landes half-sib families

Percentage of trees in classes 1 and 2 on a ranking scale from 1 (excellent) to 5 (poorest).

The Landes by Leiria half-sib cross (LSMA) from parents selected within local plantations provided some improvement in growth through selection.

Form – The one Landes family assessed for form in trial YS09 (Table 15) did not differ significantly from the Portuguese routine in proportion of acceptable straight stems in the population. In both trials, all Leirian crosses were significantly (.01 level) better than the routine in this respect.

Drought Resistance – In trial YS09 the routine, full-sib and half-sib Portuguese groups were virtually unaffected by drought death while most of the Landes families had one or more deaths attributable to this cause (Table 17).

Discussion

These two trials conclusively support previous data concerning the differences between trees of French Landes and Portuguese provenances for a wide range of soils and climatic conditions in Western Australia. The superiority of the Portuguese provenance for growth rate, tree form and drought resistance has confirmed the practice of using it for commercial planting.

Trials YS51, YS52 and YS53 – Inter Provenance Crosses at Gnangara, Yanchep and Busselton

Within the breeding program in Western Australia a limited amount of intra- and inter-provenance crossing was carried out with trees of other than Portuguese origin. Analysis of results of this work is mainly of interest to studies of species improvement and inheritance. Certain aspects however, assist to clarify the performance of major provenance groups of *P. pinaster* in Western Australia and to identify the dominant genetic characteristics of each group.

TABLE 16

Comparisons of Leirian and Landes (L) provenances for height and diameter development to age 10 years in trial YS10. The trial was planted in 1967 on fertile soils at Mundaring and samples the best sites available for the species.

RANK	AGE 3.6 YEARS HEIGHT (m)		AGE 10 YEARS DIAMETER (cm)	
	FAMILY	MEAN	FAMILY	MEAN
1	E5xE40	3.70	E5xE40	18.5
2	E19xE40	3.58	E40xE2	18.4
3	E47xE40	3.51*	E19xE40	18.3
4	E41xE40	3.44*	E28xE40	18.0
5	E28xE2	3.42*	E41xE40	17.8
6	E45xE40	3.42*	E45xE40	17.6
7	Routine	3.38*	E47xE40	17.6
8	E28xE40	3.37*	E28xE2	16.8*
9	E40xE2	3.33*	Routine	16.6*
10	MPDL	3.21*	MPDL	16.2*
11	L61238	3.14	L61104	15.2
12	L61240	3.05	L61105	15.1
13	L61104	3.00	L62347	14.8
14	L61105	2.96	L61240	14.7
15	L62347	2.83	L61238	14.5
16	L62083	2.82	L62083	14.4
17	L62090	2.77	L62069	14.1
18	L62069	2.70	L62073	14.1
19	L62065	2.70	L62065	13.7
20	L62073	2.68	L62090	13.7
LSD .05		0.18		0.70

* Not significantly different (.05 level) to the Routine.

TABLE 17

Drought damage recorded in trial YS09 in summer 1977. Stand age was 10 years. Each family contained 100 trees and each block had a total of 200 trees.

FAMILY	NUMBER OF DEAD AND DYING TREES TRIAL BLOCK NUMBER										TOTAL
	1	2	3	4	5	6	7	8	9	10	
E40xE2											0
E28xE2											0
E5xE40											0
E15xE40					1						1
E19xE40											0
E28xE40											0
E41xE40											0
E45xE40											0
E47xE40											0
LSMA											0
MPDL	1										1
L60252	2	1	1	1	2		1		1	1	10
L60253				1	1				1		3
L61103				1				1		2	4
L61104											0
L61105	2			1	1						4
L61238								1			1
L61240	1		1								2
L62065			1			1	2				4
Routine											0
TOTAL	6	1	3	4	5	1	3	2	2	3	30

Plus trees of Corsican and Landes origin selected from Western Australian plantations were crossed with plus parents of Leirian origin. The progeny were compared in three trials designed to observe the transmission of specific characters between these inter-provenance crossings.

A secondary objective was to evaluate site by provenance interaction by planting the trials at three separate geographic centres. These include yellow and grey sands of the Swan Coastal Plain north of and adjacent to Perth and poorly drained lateritic sands in the Donnybrook Sunklands, near Busselton, 250 km south of Perth. The locations tested represent the principal sites considered for *P. pinaster* afforestation within the State.

Provenances – The basic trial (Table 18) comprises 26 full-sib families, a routine bulk imported Portuguese seed batch (S5000) as a control and a seed batch from the local Joondalup seed orchard (SN5047). The 26 families comprise three groups, including 9 crosses (ExE) among superior trees from local stands of Leirian (E) origin, 9 inter-provenance crosses (ExL) between locally selected superior trees of Leirian (E) and Landes (L) origin and 8 crosses (ExC) between locally selected Leirian (E) and Corsican (C) plus trees. At one centre, Gnangara, 30 families were compared and a replacement was necessary for the family E53xL20 which was common to the other two sites.

Design – A complete randomized block design was used to replicate 5-tree line-plots for each of the 28 groups in 10 blocks at each of 3 sites.

Procedure – All stock was raised in tubes at the Wanneroo nursery and planted in June 1974 at 3 m x 3 m spacing. Superphosphate was added at the rate of 60 g per seedling at time of planting and 500 kg ha^{-1} of Agras (NP) fertilizer was broadcast in 1979. The initial low pruning was carried out to 2 m height in 1978.

Measurement – Tree heights were measured in January 1979 at age 4.5 years. Diameter at breast height, and form were measured in March 1983 at Gnangara (YS51) and Yanchep (YS52) and in April 1984 at Busselton. Form was assessed to provide values for stem straightness, forking, butt sweep, branch size and branch angle.

Results

Height and Diameter – Mean heights and diameter for each family and its ranking (R) within the trial are shown in Table 18. The data are presented in provenance groups for convenience.

The majority of the controlled crosses of acclimatized, dominant, well formed trees in local plantations have superior height and diameter growth to that of the routine batch of non-selected, non-acclimatized seed imported from Portugal. Several of the Leirian by Landes crosses (E19xL21, L13xE29) are amongst the fastest growing families in the series.

The relative growth performance of the three groups was summarized by considering the percentage of families in each provenance group which were ranked within the best one-third performers of all families (i.e. ranked 1-9).

For early height growth, the ExE crosses and ExL crosses had equal representation in the best third of families at Gnangara (44 per cent) and Busselton (33 per cent) whereas at Yanchep the proportion was 56 per cent and 33 per cent respectively. No ExC families were in the top one-third at Gnangara and Yanchep but 25 per cent were there at Busselton.

For diameter at 9 years, the ExE crosses were superior at all sites with 74 per cent of families in the best one-third. ExL had 11 per cent in the top third and ExC had 8 per cent. For both height and diameter the ExC crosses were represented in the top third only at Busselton.

The extent of these differences in growth from the routine, non-selected, Portuguese control is detailed in Table 19. Clear superiority of the Leirian provenance is emphasized by the performance of seed from the Leirian seed orchard, the mean of which did not differ significantly (.05 level) from that of the top ranked families at all three locations (Table 18).

Interaction with Site – Data for diameter at age 8 years at all three sites were subject to an analysis of variance (ANOVA). Family, block and site differences were highly significant (.001 level) but associated with a significant (.030 level) site by family interaction.

Examination of the means at each site revealed that some families had altered in relative ranking from one trial to the other suggesting favourableness for either the hotter, drier northern sites or the cooler, wetter southern site (Fig. 5). These obvious fluctuations in mean rankings were few and appeared to be mainly associated with the ExE and ExC crosses. There was a trend however, for the ExL and ExC crosses to improve relative to the dominant ExE values, with progression of trials from Yanchep to Gnangara to Busselton. All provenance crosses performed best at Busselton.

To test this possibility, for each trial the mean diameter (mean of 10 blocks) for each full-sib family, common to the three sites, was regressed against the general (environmental) mean for those families on all sites. Results in Table 20 show that up to 92 per cent of the variation in the interaction is associated with a linear relationship between family diameter at each site, and the general mean. The association is poorest at Busselton with $R^2 = 48.2$ but still highly significant. The individual regressions are significantly different and show the tendency for all families to become more comparable at Busselton ($b = 0.53$) than at Yanchep ($b = 1.40$).

To assess the extent that this trend was valid for the provenance crosses, results for the routine and orchard families were excluded from the data set. An ANOVA was carried out for 24 provenance crosses, common to the three sites, as three provenance groups each containing 8 crosses (Table 21). The site by provenance interaction was highly significant and can be largely attributable to the improvement in growth of the Corsican and Landes crosses with progressive testing south to cooler, wetter sites (Table 22).

Form – Results for the form assessment are set out in Tables 23, 24, 25 and 26. Again the families are grouped by provenance and ranked by means to aid comparisons at each of three trial locations.

The tables include separate assessments of stem straightness based initially on the percentage of stems with scores of average or better straightness (acceptable stems) and secondly on the comparison of arithmetic mean score (all points 1 to 5 are added). Similarly, mean scores for branch thickness and branch angle assessments accompany results for the percentage of better stems assessed. This latter is the system most often used in Western Australia (See Tables 6, 7, 12) as it can be directly associated with commercial acceptance of the population. For the mean score results a least significant difference (LSD) value is calculated and included in the tables.

From the rankings in Tables 23 and 24 it can be seen that for straight stems, butt sweep and normal stems (not forked and without ramicorns) the ExE crosses performed very poorly within the range of variation sampled. For straightness at Gnangara, Yanchep and Busselton, only 1, 0 and 5 of the ExE crosses respectively, were not significantly inferior to the best family. For butt sweep (Table 24) all but one of these crosses, located at Busselton, were inferior to the best family. The Corsican crosses were definitely superior in these respects with the Landes crosses intermediate in performance.

These comparisons are clarified in Table 27 in which families are grouped to show representation within the best third (1-9) of the ranking range. The high incidence of stem forks and/or ramicorns previously noted in the Portuguese populations is still clearly depicted in these results for crossings of selected plus phenotypes. In Table 27, for the combined trial results, only 4 per cent of the ExE crosses occurred in the best third of the results while 79 per cent of the Corsican were in this class.

Results for branch thickness vary with site for both the Leirian and the Corsican crosses (Tables 25, 27). At Gnangara the Leirian crosses had the smallest branches whereas the Corsican crosses were clearly superior at the

TABLE 18

Height and diameter results for provenance crosses in trials YS51, YS52 and YS53. Leirian parents are designated by E, Landes by L and Corsican by C. The routine is a commercial seed batch from the forest of Leiria.

FAMILY	HEIGHT (m) AT 4.5 YEARS						DIAMETER (cm) AT 9 YEARS					
	GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53		GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53	
	MEAN	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK
E19xE2	3.66	14	3.56	10	2.75	16	16.1	1	14.4	5	16.8	2
E19xE15	3.81	7	3.52	11	2.61	21	15.8	2	14.4	7	16.1	7
E19xE40	3.68	11	3.58	7	3.29	1	14.8	13	14.3	8	17.2	1
E53xE15	3.66	15	3.32	14	2.85	11	15.7	3	14.1	10	16.2	6
E53xE29	3.76	10	3.57	9	2.90	8	15.5	7	14.4	4	15.8	14
E53xE40	3.68	13	3.46	12	3.10	3	14.8	14	13.9	14	16.6	3
E40xE15	3.86	4	3.57	8	2.55	24	15.6	4	14.5	3	16.0	9
E41xE40	3.93	2	3.80	2	2.81	13	15.3	9	14.8	1	15.9	12
E5xE41	4.01	1	3.80	1	2.69	19	15.6	5	14.4	6	15.7	18
L13xE29	3.93	3	3.60	5	3.05	4	15.4	8	14.2	9	15.9	11
L17xEM	3.56	16	3.26	16	2.78	14	14.2	21	12.6	19	15.8	15
L20xEM	3.39	21	3.00	26	2.70	18	13.9	25	12.2	24	15.5	20
E5xL3	3.86	5	3.59	6	3.10	2	15.1	11	14.0	12	15.9	10
E19xL3	3.76	9	3.45	13	2.85	10	15.5	6	14.0	13	15.7	16
E5xL20	3.53	18	3.19	21	2.77	15	13.8	26	12.5	22	15.3	24
E19xL20	3.46	21	3.18	22	2.64	20	14.1	24	12.6	20	15.0	26
E53xL20	—	—	2.92	27	2.70	17	—	—	11.8	28	14.9	27
E19xL21	3.80	8	3.61	3	3.03	5	14.9	12	14.1	11	15.5	19
E5xC3	3.51	18	3.23	17	2.91	7	14.4	16	12.4	23	15.4	21
E19xC3	3.48	20	3.27	15	2.83	12	14.4	15	12.9	17	15.7	17
E41xC3	3.27	27	3.21	18	2.87	9	13.5	27	12.5	21	15.9	13
E53xC3	3.27	26	3.07	24	2.50	26	14.2	22	12.1	25	15.2	25
E5xC4	3.28	25	3.01	25	2.48	27	14.3	17	12.0	27	16.0	8
E19xC4	3.33	23	3.21	19	2.56	23	14.3	18	13.1	15	15.3	22
E41xC4	3.31	24	3.13	23	2.58	22	14.2	20	12.9	16	16.2	5
E53xC4	3.17	28	2.87	28	2.47	28	14.2	23	12.1	26	15.3	23
Orchard	3.84	6	3.61	4	2.93	6	15.2	10	14.7	2	16.3	4
Routine	3.55	17	3.21	20	2.55	25	14.3	19	12.7	18	14.7	28
L21xE33	3.73	12	—	—	—	—	14.9	14	—	—	—	—
LSD .05	0.28		0.20		0.42		1.00		0.71		1.02	

other two sites. Results for the Landes crosses were uniform with site. The overall result indicates that the Corsican crosses have the best branching with the Leirian and Landes crosses following in that order.

Results reveal little difference in propensity for flat angle (wide angle) branching between provenance groups (Tables 26, 27). As a group, the Corsican crosses are better with the Portuguese and Landes following in that order. The differences are of a minor nature, vary with site and are not considered to have any significance in these trials.

Differences in the number of trees with acceptable branch thickness between orchard and routine seed lots (Table 25) were not significant. Branch angles were similar for both the orchard and routine sources at each location (Table 26). Improvements of orchard stock over the routine source for stem straightness and butt sweep are, however, significant at the.05 level (Tables 23 and 24).

Discussion

Replication of the trial at the three centres gives consistent results for the major attributes of provenances measured in previous trials. Characteristics for vigour in height and diameter growth are dominant in the Portuguese (ExE) crosses while the major defects noted in the form of the species are still present in them. The favourable aspects of these latter attributes are dominant in the Corsican crosses as they were in

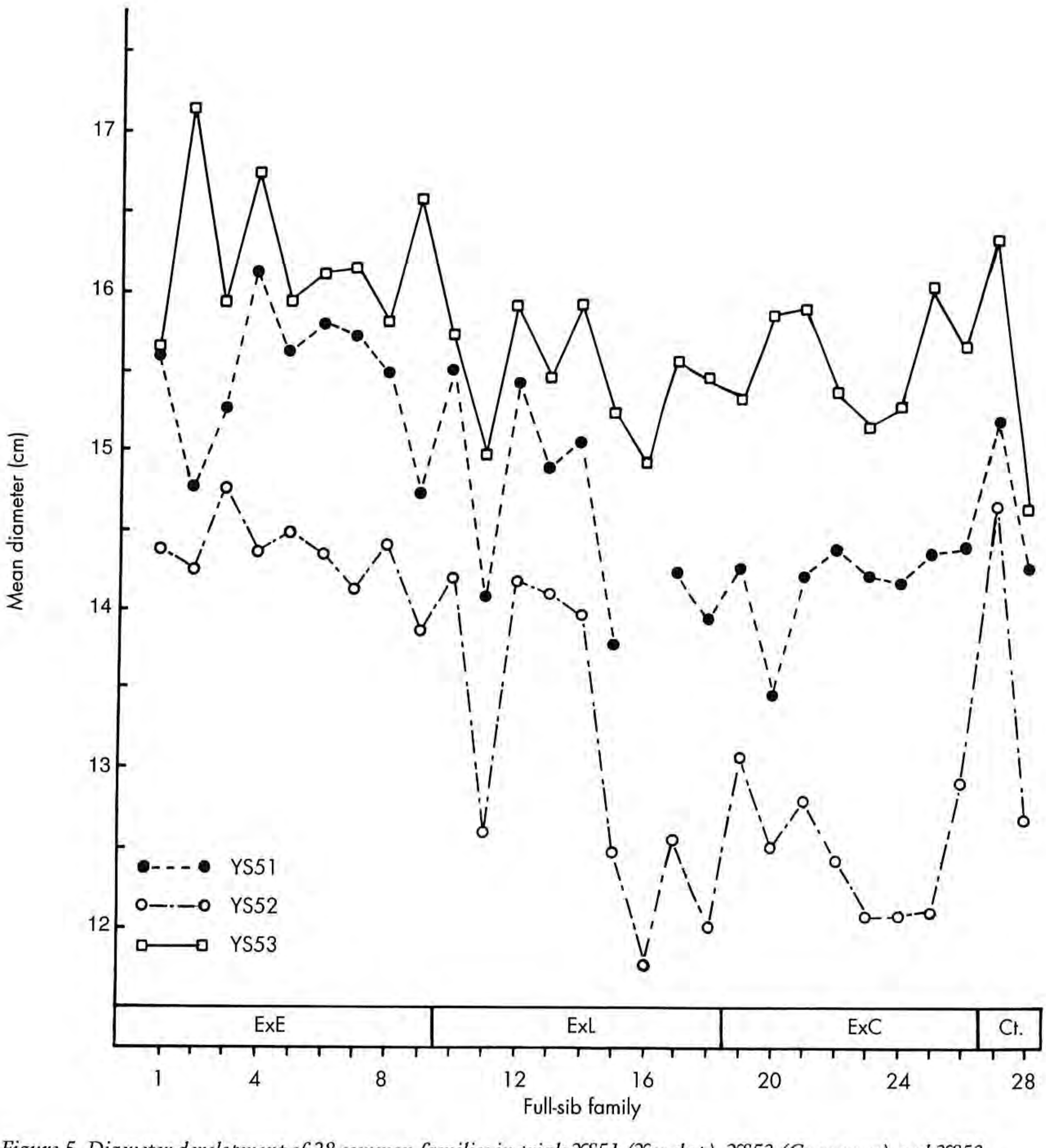

Figure 5. Diameter development of 28 common families in trials YS51 (Yanchep), YS52 (Gnangara) and YS53 (Busselton) comparing performance of Leirian crosses (ExE), Leirian and Landes crosses (ExL) and Leirian and Corsican crosses (ExC). Families 27 and 28 (Ct.) are the seed orchard and routine controls.

this provenance in previous tests (See Tables 6, 7). Consistency of the results over the range of sites and the dominance of these specific attributes following inter-provenance crossing confirms that these are features of geographic races and strongly inherited.

Corsican crosses displayed desirable branch angle and branch size but these were not very different from the Leirian crosses. The negligible improvement in these attributes in the seed orchard stock indicates lower heritabilities and limited scope for selection within the provenance range. The family E5xE41, the highest ranked family for branch thickness (Table 25), and family E41xE40 are ranked high for branch angle. These two attributes can obviously be improved to the maximum for the species from within variation in the Portuguese population.

The establishment of the trials over the range of sites shows the tendency for the genotypes of the Corsican and, to a lesser extent, the Landes provenance to favour diameter development under more southern, cooler, wetter conditions.

The trials extend comparisons of provenances to the cooler, southern sites near Busselton. The performance of the seed orchard stock shows that considerable

TABLE 19

Variation in height and diameter from values for Routine imported Portugese seed for inter- and intra-provenance crosses in trials YS51, YS52 and YS53.

PROVENANCE	HEIGHT AT 4.5 YEARS		DIAMETER AT 9 YEARS	
	MEAN (m)	% DIFFERENCE FROM ROUTINE	MEAN (cm)	% DIFFERENCE FROM ROUTINE
GNANGARA (YS51)				
Leiria x Leiria	3.80	7	15.5	9
Leiria x Landes	3.70	4	14.7	4
Leiria x Corsican	3.30	-7	14.2	0
Seed Orchard Leiria	3.85	8	15.2	7
Routine Leiria	3.55	0	14.2	0
YANCHEP (YS52)				
Leiria x Leiria	3.58	12	14.4	13
Leiria x Landes	3.33	4	13.1	3
Leiria x Corsican	3.13	2	12.5	-2
Seed Orchard Leiria	3.61	12	14.7	16
Routine Leiria	3.21	0	12.7	0
BUSSELTON (YS53)				
Leiria x Leiria	2.84	11	16.2	10
Leiria x Landes	2.85	12	15.4	5
Leiria x Corsican	2.65	4	15.6	6
Seed Orchard Leiria	2.94	15	16.4	12
Routine Leiria	2.55	0	14.7	0
COMBINED				
Leiria x Leiria	3.41	10	15.4	11
Leiria x Landes	3.29	6	14.4	4
Leiria x Corsican	3.03	-2	14.1	1
Seed Orchard Leiria	3.47	12	15.4	11
Routine Leiria	3.10	0	13.9	0

TABLE 20

Values for regression (y = a + bx) of the mean diameter for families, at each site, in trials YS51, YS52 and YS53 against the general (environmental) mean obtained for the families over the three sites. The Routine, orchard and non common crosses have been omitted.

TRIAL	COEFFICIENT B	S.D OF B	CONSTANT A	S.D. ABOUT REGRESSION	R^2	N
YS51 Gnangara	1.07	1.28	-0.96	0.28	86.7	23
YS52 Yanchep	1.40	0.09	-7.13	0.27	92.0	23
YS53 Busselton	0.53	0.11	8.09	0.35	48.2	23

TABLE 21

ANOVA for diameter at age 9 years for provenance crosses in trials YS51, YS52 and YS53. The analysis is for full-sib families common to the three trials and for three provenance groups Leiria x Leiria, Leiria x Landes and Leiria x Corsican.

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARE	VARIANCE RATIO	SIGNIFICANCE
FULL-SIB FAMILIES				
Site	2	350.00	30.39	0.000
Block (Site)	27	11.52	10.57	0.000
Families	23	12.99	11.93	0.000
Site x Families	46	2.15	1.94	0.000
Error	621	1.09		
Total	719			
PROVENANCE GROUPS				
Site	2	350.00	30.39	0.000
Block (Site)	27	11.52	9.50	0.000
Provenance	2	104.59	86.26	0.000
Site x Provenance	4	8.84	7.29	0.000
Error	684	1.21		
Total	719			

improvement in height and diameter and stem straightness and absence of forking has been obtained in the early selection program for Portuguese material. The relatively high standards achieved by the Corsican crosses for stem straightness, absence of butt sweep and absence of forks show there is considerable scope for improvement to meet the population limits for the species under Western Australian conditions.

The dominance and inheritance of provenance characteristics on crossing with Leirian stock are summarized in Table 27. This analysis assists to quantify the consistency and strength of expression of attributes for plant vigour and form of the three provenance groups Leirian, Landes and Corsican. The Landes group is intermediate between the outstanding vigour of the Leirian provenance and the excellent form of the Corsican provenance. Although inferior in vigour to the Leirian population it is slightly superior to that population in the absence of forks and butt sweep.

Inter-provenance crossing supports other provenance tests carried out in Western Australia. It verifies that the height, diameter and volume advantage of the Portuguese provenance is consistent over the range of climate and soils which could be available for afforestation in Western Australia. Controlled crosses of Leirian parents with selected Landes and Corsican material (which has been acclimatized) provide vigour at least equal to that of the unselected Portuguese imports. Selected crosses with Landes parents may produce hybrid families with vigour akin to that of Leirian crosses (i.e. L13xE29). However, apart from perhaps improving frost resistance, reasons for such a

TABLE 22

Mean diameters for provenance crosses of Leiria x Leiria (ExE), Leiria x Landes (ExL) and Leiria x Corsican (ExC) in trials YS51, YS52 and YS53 at Gnangara, Yanchep and Busselton. Values in brackets denote the mean of the cross as a percentage of the dominant Leirian x Leirian group at the same site.

PROVENANCE GROUP	MEAN DIAMETER AT EACH SITE (cm)			GROUP MEAN
	YANCHEP	GNANGARA	BUSSELTON	
Leiria x Leiria	14.40 (100)	15.56 (100)	16.20 (100)	15.39
Leiria x Landes	13.27 (92)	14.61 (94)	15.58 (96)	14.49
Leiria x Corsican	12.50 (87)	14.81 (91)	15.61 (96)	14.10
LSD 0.01		0.04		
Latitude	31°25'	31°43'	33°46'	
Longitude	115°42'	115°54'	115°37'	

cross for Western Australian conditions are not apparent.

Results for the ranking of form characteristics from the inter-provenance crosses indicate strong inheritance of aspects of form ascribed to different provenances in previous studies. There are very marked differences between the populations.

The Corsican race carried many aspects of its superior form into the inter-racial crosses. It is significant that the high propensity for forking and ramicorns observed for the Portuguese source is still evident after the first generation of selection and crossing. However, the plus trees used in this trial are not elite and of a quality suitable for orchard production. Parents E2, E15, and E52 used in the early crossing trials have subsequently been excluded from the orchard program owing to their proven transmission of poor form characteristics.

In conclusion, the comparisons of the inter-provenance crosses show a tendency for the Corsican and, to a lesser extent, the Landes genotype to adaptation favourable in diameter growth to cooler, moister conditions.

FLOWERING CHARACTERISTICS

Introduction

Perry (1940, 1949) compared the timing of pollen development of imported seed lots of *Pinus pinaster* grown in plantation stands on the Swan Coastal Plain near Perth. Under conditions of similar climate, soils and culture the flowering behaviour of major geographic provenance groups was distinctive as follows:

1. Portugal – Staminate inflorescences began to appear in mid-August and pollen shed commenced in early September. All pollen was shed by the end of September.
2. French Landes – Staminate flowers began to appear by early September and were fully mature by early October. Pollen was dispersed by the end of October.
3. French Esterel – Staminate flowers were produced in profusion by mid-September and were fully mature by mid-October.
4. Corsican – Staminate flowers were few, appeared about the middle of October and were shedding pollen by the end of the month.

Following a visit to Portugal and France, Perry noted the impact of latitude and altitude on time of flowering (Perry and Hopkins 1967).

Detailed observation of flowering bud receptivity was part of the breeding crossing program for *Pinus pinaster* in Western Australia. Pollination was carried out in a scion arboretum where clonal variation in flower inception and receptivity to pollen is recorded over a period of years. Quantitative data on the propensity for flowering and cone production at a young age was also available from established provenance trials.

Procedure

Flowering Receptivity

Times for the receptivity of female flowers to pollen were recorded during the controlled crossing program at the Neaves Road Scion Arboretum near Perth. The arboretum, maintained for grafts of plus phenotypes of Portuguese stock, contained some clones of Landes and Corsican parents selected from local stands. All grafts were made with scions of mature trees grafted on to stocks of Portuguese origin.

TABLE 23

Assessment results for stem straightness for trials YS51, YS52, YS53. Trees were ranked on a scale of 1 (excellent) to 5 (poorest). The Routine is a commercial seed lot from Leiria.

FAMILY	STRAIGHTNESS (% CLASS 1,2,3)						STRAIGHTNESS (MEAN OF SCORES)					
	GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53#		GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53	
	%	RANK	%	RANK	%	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK
E19xE2	42	24	64	16	40	25	3.56	24	3.32	17	2.66	25
E19xE15	31	28	46	26	35	26	3.70	28	3.54	25	2.70	27
E19xE40	51	11	40	28	61	12	3.42	10	3.60	28	2.35	11
E53xE15	51	11	66	15	57	17	3.50	15	3.26	14	2.39	13
E53xE29	46	16	61	18	64	9	3.50	15	3.34	18	2.28	9
E53xE40	44	20	60	19	59	15	3.48	13	3.38	20	2.43	17
E41xE15	40	26	44	27	61	12	3.60	26	3.54	25	2.33	10
E41xE40	41	25	54	22	64	9	3.56	24	3.44	22	2.36	12
E5xE41	58	6	58	21	46	21	3.34	8	3.38	20	2.54	21
L13xE29	55	9	68	13	74	5	3.42	10	3.20	10	2.20	5
L17xEM	38	27	49	24	35	26	3.62	27	3.46	23	2.67	26
L20xEM	51	11	70	11	52	19	3.45	12	3.22	11	2.52	20
E5xL3	46	16	60	19	57	17	3.48	13	3.34	18	2.43	17
E19xL3	47	15	52	23	44	23	3.54	20	3.48	24	2.60	23
E5xL20	58	6	82	5	45	22	3.32	6	3.04	6	2.55	22
E19xL20	44	20	72	10	43	24	3.54	20	3.24	12	2.61	24
E53xL20	—	—	86	2	52	19	—	—	3.02	4	2.50	19
E19xL21	21	30	70	11	60	14	3.78	29	3.28	16	2.40	14
E5xC3	58	6	64	16	71	7	3.24	2	3.24	12	2.27	8
E19xC3	59	5	84	3	73	6	3.32	6	2.96	2	2.21	6
E41xC3	61	4	84	4	79	2	3.34	8	2.86	1	2.17	2
E53xC3	65	2	88	1	78	4	3.24	2	2.96	2	2.14	1
E5xC4	55	9	74	9	59	15	3.30	4	3.14	8	2.41	16
E19xC4	44	20	78	6	79	2	3.54	20	3.14	8	2.19	4
E41xC4	45	18	78	7	71	7	3.50	15	3.08	7	2.25	7
E53xC4	76	1	76	8	80	1	3.12	1	3.02	4	2.18	3
Orchard	64	3	68	13	62	11	3.30	4	3.26	14	2.40	15
Routine	22	29	48	25	28	28	3.80	30	3.54	25	2.77	28
L21xE33	45	18	—	—	—	—	3.54	20	—	—	—	—
LSD .05							0.22		0.23		0.22	
.01							0.29		0.30		0.30	

% Class 1,2 trees only.

TABLE 24

Assessment results for butt sweep and percentages of single (normal) stems in trials YS51, YS52, YS53. Families are ranked within trials. The Routine is a commercial seed lot from Leiria.

	BUTT SWEEP						PERCENTAGE OF SINGLE STEMS					
FAMILY	GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53		GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53	
	MEAN	RANK	MEAN	RANK	MEAN	RANK	%	RANK	%	RANK	%	RANK
E19xE2	2.66	27	2.66	19	3.21	28	26	27	62	16	26	28
E19xE15	2.40	22	2.96	27	3.07	27	31	22	52	25	54	19
E19xE40	2.32	13	2.70	22	2.85	23	37	15	40	28	35	27
E53xE15	2.54	26	2.60	17	2.61	16	57	2	72	11	53	20
E53xE29	2.36	16	2.62	18	2.62	17	34	17	55	23	55	18
E53xE40	2.24	11	2.56	16	2.65	18	33	19	56	22	65	12
E41xE15	2.34	14	2.78	24	2.57	14	26	27	50	26	53	20
E41xE40	2.36	16	2.68	20	2.40	4	27	26	62	16	52	22
E5xE41	2.35	16	2.50	15	2.56	12	31	22	54	24	46	25
L13xE29	1.95	1	2.08	2	2.26	1	25	24	62	16	63	13
L17xEM	2.34	14	2.68	20	2.85	23	23	29	57	21	61	15
L20xEM	2.36	16	2.44	13	2.80	20	43	11	74	10	72	6
E5xL3	2.22	9	2.30	9	2.53	9	34	17	58	20	51	23
E19xL3	2.68	28	2.92	26	3.00	25	29	24	64	14	69	10
E5xL20	2.22	9	2.38	12	2.45	5	44	9	82	2	57	17
E19xL20	2.70	29	2.86	25	3.04	26	36	16	86	1	71	7
E53xL20	—	—	2.36	10	2.87	19	—	—	80	6	73	5
E19xL21	2.48	25	2.76	23	2.83	21	33	19	64	14	63	13
E5xC3	2.04	2	2.10	3	2.33	3	38	14	60	19	71	7
E19xC3	2.05	4	2.12	5	2.56	12	47	5	82	2	75	3
E41xC3	2.04	2	1.83	1	2.49	6	47	5	69	12	60	16
E53xC3	2.09	5	2.26	8	2.49	7	55	3	82	2	78	2
E5xC4	2.14	6	2.14	6	2.59	15	45	8	80	6	80	1
E19xC4	2.28	12	2.10	3	2.55	10	44	9	78	8	68	11
E41xC4	2.38	20	2.36	10	2.50	8	51	4	82	2	71	7
E53xC4	2.18	7	2.22	7	2.30	2	73	1	76	9	74	4
Orchard	2.18	7	2.48	14	2.55	10	46	7	66	13	51	23
Routine	2.82	30	3.00	28	2.84	22	22	30	48	27	44	26
L21xE33	2.42	24	—	—	—	—	33	19	—	—	—	—
LSD .05	0.25	0.31	0.29									
.01	0.33	0.41	0.39									

TABLE 25

Comparisons of branch thickness for families in trials YS51, YS52, YS53. Trees were scored on a scale of 1 (finest branching) to 5 (coarsest branching). The Routine is a commercial seed lot from Leiria. Families are ranked within trials.

FAMILY	BRANCH THICKNESS (% CLASS 1,2,3)						BRANCH THICKNESS (MEAN OF SCORES)					
	GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53*		GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53	
	%	RANK	%	RANK	%	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK
E19xE2	70	14	76	19	32	23	3.28	14	3.30	19	2.70	15
E19xE15	53	19	64	24	33	22	3.44	18	3.34	24	2.80	22
E19xE40	84	4	76	15	50	5	3.12	5	3.22	12	2.59	5
E53xE15	43	26	72	18	35	20	3.56	25	3.28	18	2.76	20
E53xE29	34	30	73	17	40	12	3.66	28	3.27	17	2.74	18
E53xE40	76	9	80	10	35	20	3.22	8	3.20	11	2.71	17
E41xE15	82	5	70	19	47	6	3.14	6	3.30	19	2.59	6
E41xE40	82	5	80	10	40	12	3.04	3	3.16	7	2.62	9
E5xE41	98	1	82	8	67	1	2.76	1	3.16	7	2.35	1
L13xE29	45	24	44	27	37	16	3.54	22	3.56	27	2.83	23
L17xEM	73	11	90	3	30	24	3.26	13	3.11	4	2.85	24
L20xEM	51	20	66	23	28	27	3.48	20	3.32	22	2.86	25
E5xL3	92	2	74	16	63	2	3.02	2	3.26	16	2.39	2
E19xL3	35	28	50	26	25	28	3.68	30	3.50	26	2.98	28
E5xL20	76	9	88	5	36	19	3.22	8	3.12	5	2.74	18
E19xL20	51	20	60	25	29	25	3.54	22	3.40	25	2.96	27
E53xL20	—	—	70	19	29	25	—	—	3.30	19	2.94	26
E19xL21	56	18	44	27	42	9	3.44	18	3.56	27	2.69	13
E5xC3	88	3	96	1	56	3	3.08	4	3.04	1	2.46	3
E19xC3	57	17	86	6	42	9	3.40	17	3.14	6	2.60	7
E41xC3	78	7	94	2	43	7	3.24	11	3.06	2	2.68	12
E53xC3	49	22	78	12	37	16	3.52	21	3.22	12	2.69	14
E5xC4	78	7	90	3	51	4	3.22	8	3.10	3	2.55	4
E19xC4	44	25	82	8	43	7	3.56	25	3.18	10	2.62	8
E41xC4	65	15	78	12	38	15	3.36	15	3.22	12	2.71	16
E53xC4	35	28	78	12	42	9	3.66	28	3.22	12	2.66	11
Orchard	72	12	84	7	40	12	3.24	11	3.16	7	2.66	10
Routine	63	16	68	22	37	16	3.32	15	3.32	22	2.77	21
L21xE33	41	27	—	—	—	—	3.60	27	—	—	—	—
LSD .05							0.18		0.18		0.25	
.01							0.24		0.24		0.33	

* % Class 1,2 trees only.

TABLE 26

Assessment of branch angle for trials YS51, YS52, YS53. Trees were scored on a scale of 1 (widest angle) to 3 (steepest angle). The Routine is a commercial seed lot from Leiria. Families are ranked in each trial.

FAMILY	BRANCH ANGLE (% CLASS 1,2) GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53		BRANCH ANGLE (MEAN OF SCORES) GNANGARA YS51		YANCHEP YS52		BUSSELTON YS53	
	%	RANK	%	RANK	%	RANK	MEAN	RANK	MEAN	RANK	MEAN	RANK
E19xE2	22	8	10	26	38	22	2.82	8	2.94	25	2.68	22
E19xE15	29	7	24	13	43	17	2.74	7	2.80	14	2.57	16
E19xE40	39	3	28	8	65	3	2.66	3	2.72	6	2.37	3
E53xE15	6	24	16	24	43	14	3.16	28	2.84	19	2.55	13
E53xE29	6	24	22	16	40	20	3.10	25	2.82	17	2.60	20
E53xE40	20	13	26	9	55	7	2.94	14	2.80	14	2.45	7
E41xE15	20	13	24	13	41	18	2.88	10	2.78	12	2.59	18
E41xE40	41	2	34	4	48	11	2.64	2	2.66	2	2.54	11
E5xE41	67	1	34	4	40	20	2.36	1	2.72	6	2.60	21
L13xE29	10	22	26	9	59	4	3.00	21	2.76	8	2.46	8
L17xEM	21	12	29	7		17	2.94	14	2.76	8	2.59	17
L20xEM	16	16	18	22	44	15	3.02	22	2.90	23	2.56	14
E5xL3	10	22	20	19	53	9	3.06	24	2.92	24	2.47	10
E19xL3	6	24	14	25	19	28	3.04	23	2.94	25	2.88	28
E5xL20	22	8	38	2	53	9	2.84	9	2.66	2	2.45	5
E19xL20	16	16	22	16	41	18	2.96	17	2.78	12	2.59	18
E53xL20	—	—	38	2	27	27	—	—	2.66	2	2.77	27
E19xL21	35	4	18	22	14	15	2.70	5	2.88	22	2.56	15
E5xC3	34	5	32	6	79	1	2.68	4	2.68	5	2.17	1
E19xC3	33	6	26	9	58	5	2.72	6	2.76	8	2.46	9
E41xC3	16	16	20	19	66	2	2.96	17	2.86	21	2.34	2
E53xC3	22	8	40	1	29	25	2.90	11	2.60	1	2.71	24
E5xC4	22	8	22	16	57	6	2.94	14	2.80	14	2.43	4
E19xC4	15	21	8	27	55	7	2.90	11	2.96	27	2.45	5
E41xC4	4	28	8	27	50	10	3.18	29	3.00	28	2.54	12
E53xC4	6	24	20	19	28	26	3.12	26	2.82	17	2.74	25
Orchard	18	15	26	9	34	24	2.96	17	2.76	8	2.77	26
Routine	16	16	24	13	37	23	2.90	11	2.84	19	2.70	23
L21xE33	4	28	—	—	—	—	3.12	26	—	—	—	—
LSD .05							0.20		0.20		0.22	
.01							0.27		0.26		0.29	

TABLE 27

Proportion of families from provenance crosses with superior growth and form characteristics assessed in trials YS51, YS52, YS53. The Leiria and Landes means are from 9 families, the Corsican is from 8 families and show the percentage representation of each provenance group in the best one-third of families i.e. within ranking 1 to 9.

TREE CHARACTERISTIC ASSESSED	FAMILY CROSSED WITH LEIRIA	PERCENTAGE OF FAMILIES RANKED IN THE TOP ONE-THIRD OF THE TRIAL — TRIAL REPLICATION			
		GNANGARA	YANCHEP	BUSSELTON	COMBINED
Stem Height (3.5 years)	Leiria	44	56	67	56
	Landes	44	33	0	26
	Corsica	0	0	25	8
Stem Diameter (9.5 years)	Leiria	78	78	67	74
	Landes	22	11	0	11
	Corsica	0	0	25	8
Stem Straightness (Means of Point Scores)	Leiria	11	0	11	7
	Landes	11	22	11	15
	Corsica	75	87	87	83
Stem Straightness (Percentage of Class 1,2,3 Trees)	Leiria	11	0	22	11
	Landes	22	22	11	19
	Corsica	75	87	87	83
Butt Sweep (Means of Point Scores)	Leiria	0	0	11	4
	Landes	33	22	33	30
	Corsica	75	77	63	75
Single Stems (Percentage without Forks or Ramicorns)	Leiria	11	0	0	4
	Landes	11	33	33	26
	Corsica	77	75	75	79
Small Branch Thickness (Percentage of Class 1,2,3 Trees)	Leiria	56	11	33	33
	Landes	22	22	22	22
	Corsica	38	63	75	58
Flat Branch Angle (Percentage of Class 1,2 Trees)	Leiria	56	44	22	41
	Landes	22	44	33	33
	Corsica	50	37	62	50

Fruitfulness

The percentages of trees carrying male and female strobili at age 5.5 years, and bearing cones at 10.5 years of age were recorded in trial 3/65 (Table 1) at Gnangara plantation.

Results

Flower Receptivity

Pollination records for a range of clones and five seasons, from 1965 to 1970, are contained in Table 28. The clonal record in any one year includes several ramets and observations on up to 26 female flowers.

In Figure 6 a line is drawn from the data for individual clones to represent the period from when the first female flower was receptive until the last flower isolated had closed its scales.

From Figure 6 it is obvious that the Portuguese provenance is the first to become receptive to pollen in spring and the Corsican is the last. The Landes trees occupy a position in between these two extremes. There is considerable clonal variation within provenance groups and some variation between seasons (i.e. much earlier flowering in 1968 and 1970).

Fruitfulness

Results from trial 3/65 at age 5.5 years (See Table 5) showed the highest percentage of flowering trees to be in the Leirian provenances. The Italian seed lot had the next greatest number of young trees with cones and was significantly greater than the Corsican and Landes seed lots. For pollen development at this age the Landes, Corsican and Italian provenances were significantly poorer than the Leirian trees.

At age 10.5 years (Table 6) the Leirian routine and Italian seed lots again had the most cone producing trees and were significantly greater than the Leirian 2 seed lot. The Landes and Corsican trees continued to have the least cone bearing trees at this age.

Discussion

Flowering Times

The clonal ranges shown in Figure 6 represent the period from the first record of receptivity of the first flower produced by the clone until the last flower isolated had closed its scales. Each flower is usually receptive for a period of approximately 10 days. Release of pollen was not recorded but it is of the order of 10 days after the first female flower on the ramet becomes receptive. Pollen flies for 5 to 10 days from a single tree, depending on weather conditions.

The crossing program, which aimed to obtain a quota of successful pollinations for each clone provides details for the inception of flower receptivity for all clones. Records do not, however, cover all conelets produced and it is possible that the length of the receptive period in any one clone in any one season could be longer than that recorded. This possibility is partly accounted for by presenting the pattern within different seasons and including the same clone in different seasons, wherever possible.

The strip comparison trial XRI (Table 1) also proved ideal for comparing the flowering times of various provenances. The several Portuguese and two Spanish provenances from the northern coastal plain, included in the trial, flowered at the same time producing heavy crops of pollen in early September 1988 (age 22 years). Some Landes groups ripened next, flowering heavily and shedding at peak just as the process for the Portuguese was terminating. Tunisian trees followed, just after the peak for the Landes trees, in late September. The Italian trees flowered sparsely and pollen shed did not begin until mid-October. The Corsican provenance also shed lightly at about the same time.

The Landes provenance S2865, used in trial 3/65 and incorporated in the strip comparison, did not begin to shed pollen until most other Landes seed lots had terminated. It was obvious from tree appearance and time of pollen shed that this group is more akin to the Corsican race than to the usual Landes groups.

These recent studies confirm the general trends reported by Perry. They reveal, however, great variation between genotypes within a population and overlapping flowering times between some provenance groups. Results suggest that provided the population sample is representative and environmental conditions are similar, the three provenance groups will show distinctive flowering patterns.

The relatively early flowering of the Corsican clones in the 1970 results (Fig. 6) were rather unexpected and associated with an early spring.

In practice it is unlikely that Portuguese material could naturally cross with Corsican stock but crossing with Landes and Landes with Corsican is quite possible (where geographic separation of populations does not exist). Little success was obtained in initial attempts to cross Portuguese with Corsican trees by applying Portuguese pollen to Corsican female conelets. Crossing between the provenances was only readily obtained by applying stored Corsican pollen to receptive Portuguese flowers. It is possible that there could be natural incompatibility between Portuguese pollen and Corsican conelets.

Precocious Cone Development (Fruitfulness)

Results shown in Table 5 separated the Leiria provenances from the slower growing Italian provenance on percentage of trees bearing cones at age 5.5 years. Differences are significant at the .05 level. The Landes and Corsican groups are similar and significantly less in this respect than the other provenances in the trial.

TABLE 28

Pollination record for clones of Leirian (E), Landes (L) and Corsican (C) provenances within the Neaves Road Scion Arboretum.

YEAR	CLONE	NUMBER OF RAMETS USED	NUMBER OF POLLEN EXCLOSURES	DATE POLLINATION COMMENCED	DATE POLLINATION TERMINATED	NUMBER OF CONES PRODUCED
1965	E14	7	23	8/9	16/9	20
	E16	5	20	8/9	15/9	29
	E34	14	23	2/9	20/9	38
	E40	13	29	8/9	16/9	60
	L70	9	9	24/9	1/10	19
	L26	8	8	24/9	29/9	27
	C2	1	1	15/10	19/10	0
	C3	3	4	29/9	22/10	3
1966	E14	4	13	5/9	20/9	10
	E28	9	14	8/9	22/9	22
	E40	3	13	5/9	15/9	22
	E47	4	18	5/9	22/9	30
	L26	1	8	30/9	5/10	16
	C2	1	1	17/10	21/10	1
	C3	4	7	14/10	21/10	0
1967	E8	5	6	4/9	26/10	8
	E16	5	8	11/9	2/10	10
	E19	6	16	11/9	26/9	30
	E37	2	15	11/9	26/9	34
	L3	4	6	2/10	23/10	11
	L13	6	14	4/9	13/10	14
	L17	5	13	26/9	22/10	11
	L20	4	13	11/9	27/10	5
	L21	4	5	11/9	14/9	2
	C2	1	1	19/9	26/9	0
	C3	3	7	19/9	13/10	0
	C6	1	1	18/10	27/10	1
1968	E19	6	12	28/8	16/9	23
	E47	4	8	28/8	16/9	10
	E58	3	5	3/9	26/9	17
	E118	4	4	28/8	12/9	3
	L3	2	5	12/9	26/9	11
	L17	4	4	3/9	23/9	9
1970	107	3	9	28/8	1/10	11
	E108	2	9	28/8	18/9	14
	E118	2	4	28/8	18/9	4
	E128	2	8	28/8	9/9	9
	E135	2	5	31/8	15/9	13
	L17	1	6	18/9	1/10	9
	L20	4	7	9/9	28/9	9
	L21	1	1	14/9	28/9	0
	C2	1	1	14/9	21/9	0
	C3	4	19	9/9	28/9	0

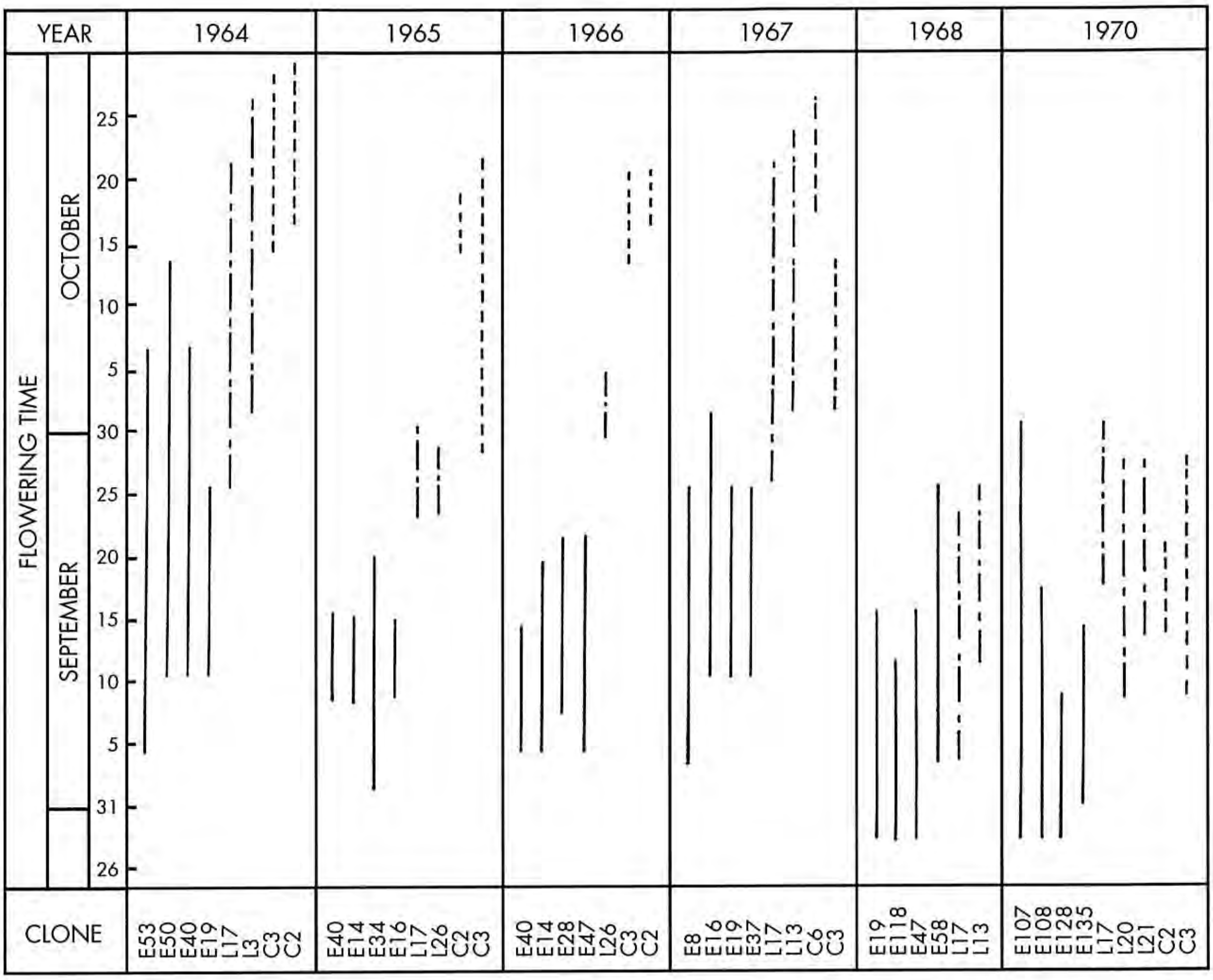

Figure 6. Variation in flower receptivity of clones of three provenances in the Neaves Road Scion Arboretum. The period of receptivity for each clone is designated by the lines in the graph. Clone identification beginning with E refers to Leirian origin, L refers to Landes origin and C refers to Corsican origin.

Sampling age is shown to be important within the Portuguese seed lots in data presented in Tables 5 and 6. At age 10.5 years the Leiria R exceeded the Leiria 2 source in the proportion of trees with cones. Both lots were equivalent at age 5.5 years while Leiria 2 had the most cone bearing trees at age 4.5 years. These differences are minor in nature.

The representativeness of the seed lot must be considered. The Landes provenance in trial 3/65 was similar in height growth, form and flowering characteristics to the Corsican (Tables 5 and 6). However, the wide range of comparisons of these two provenances in Western Australia (Hopkins 1960) usually showed the Landes provenance to have a height advantage over the Corsican and the form characteristics of Landes sources to be more like the Portuguese than the Corsican. Examination of the flowering time for the Landes population concerned in trial 3/65, left little doubt that it is more like the Corsican group than the general Landes groups. This could account for the unexpectedly low fecundity recorded for the Landes provenance in this trial and the rather high order of stem straightness also recorded for the group.

Conclusion

Results obtained within the improvement program quantify variation associated with flowering time and precocity in some provenances of *Pinus pinaster*. Differences are obviously due to genetic control within populations. The Portuguese stock is the first to flower in spring, under Western Australian conditions, and the Corsican is the last to flower. The differences between the two are distinct in the cases measured. The Landes provenance flowers in between these two extremes, is followed by the Tunisian, then the Italian and Corsican.

The Landes and Corsican provenances studied showed less precocity at age 5.5 years than Portuguese and Italian seed lots and had significantly less trees with cones at age 10.5 years.

SIGNIFICANCE OF PROVENANCE VARIATION TO TREE IMPROVEMENT

Introduction

The improvement program for *P. pinaster* in Western Australia began in 1957 (Hopkins and Butcher 1992) and work was centred on the Portuguese provenance for improvement of stem straightness, branching characteristics and uniformity of the commercial tree. The possible contribution of other provenances to improvement in stem straightness, hybrid vigour, branch size, spiral grain, wood density and drought resistance required consideration. In this section results of local evaluations are summarized and reviewed with respect to improvement possibilities for the species.

Tree Vigour

Leirian, Landes, Corsican, Italian Provenances

Three field trials, 3/65, XS12 and XS09 (Table 1), compare major provenance groups from Portugal, Landes, Italy and Corsica.

Trial 3/65 compared the performance of Leiria, Landes, Corsican and Italian provenances and was established at Gnangara plantation in 1964. Growth in the Leirian provenance was significantly greater in height, diameter and volume than in the other provenances, which were similar to each other (Table 4). At age 21 years Landes, Corsican and Italian provenances were 26, 29 and 37 per cent poorer in height growth and had less than half the stem volume of the Portuguese trees.

Growth of the Leiria, Landes and Corsican provenances is also compared in trial XS12 at Yanchep. The trial has 10 families (Table 29) and is well replicated to provide comparisons of both inter- and intra-provenance variation for the major groups. The site has a limestone influence and is more drought-prone than that tested in trial 3/65.

At age 19.5 years (Fig. 7, Table 29) the Landes and Corsican representatives were 19 and 31 per cent respectively poorer in height growth than the Portuguese routine and 51 and 57 per cent less in volume growth. The Landes families are from French collections of half-sib seed from plus trees. Corsican seed came from good stands in the vicinity of Vivario, Porto-Vecchio, Zonza and Ghisoni and represents an altitudinal range from 700 to 900 m.

The MPDL family in trial XS12 (Table 29) is a mixture of half-sib seed from plus trees selected in Portugal (Perry and Hopkins 1967). Average performance was not significantly different from that of the routine source which was bulk collected in the forest of Leiria. The plus trees, selected as dominants or codominants but mainly to favour stem straightness and improved branching, retained their natural vigour in the environmental change. Controlled crosses from plus stems selected in local stands of Portuguese origin (E5xE40, E19xE40) have a 20 per cent increase in tree volume over the non-selected routine (Table 7), at age 20 years (Table 29).

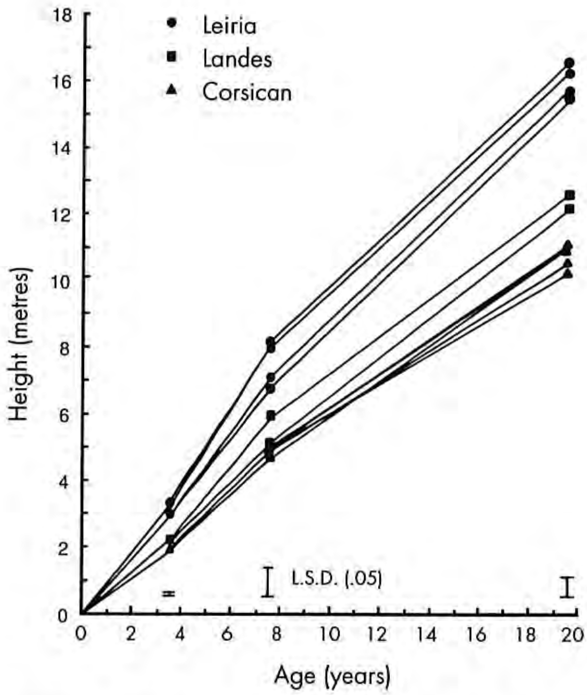

Figure 7. Height growth of provenances in trial XS12. The levels of difference between means, significant at the .05 level of probability, are included for each measurement.

These differences in growth performance between geographic groups occurred from seedling to semi-mature stand (Fig. 7).

Portuguese, Tunisian, Spanish Provenances

The superiority in vigour of the Portuguese provenances was also found to exist over 24 half-sib Tunisian families from Ain Baccouch in trial XS09 at Gnangara (Table 9). In this trial no significant differences between the routine seed lot from Leiria and two Spanish provenances, collected on the north-west coast near Barreiros (north) and La Toja (west), could be found. At the time of collection the latter were considered to be similar in appearance to stands at Leiria (Perry and Hopkins 1967).

The Barreiros provenance was also tested on limestone soils in the partly controlled trial (XR1) at Yanchep and found to have similar height and diameter growth to the Leirian routine (Table 10). In this comparison of adjacent strips on drought-prone soils the Tunisian half-sib lots were again significantly inferior in height and diameter growth to the Leiria routine (See Table 10, Fig.4).

TABLE 29

Performance of provenance groups in trial XS12 on limestone sands at Yanchep. The mean result for each provenance has been expressed as a percentage deviation from the Leirian Routine control.

PROVENANCE GROUP	STEM STRAIGHTNESS ACCEPTABLE %	AGE 19.5 YEARS MEAN HEIGHT (m) (m² ha⁻¹)	MEAN BAOB (m³ ha⁻¹)	MEAN VOLUME %	DROUGHT LOSSES
Leiria Improved					
E5xE40	79	16.5	25.21	149	0.0
E19xE40	81	16.3	25.92	147	0.6
MPDL	75	15.8	24.92	139	1.1
Mean	78	16.2	25.35	145	0.6
Deviation	(+29)*	(+5)	(+14)	(+21)	(-65)
Leiria Routine	61	15.4	22.12	120	1.7
Deviation	(0)	(0)	(0)	(0)	(0)
Landes					
L64445	85	12.6	14.29	62	12.8
L64435	76	12.2	12.96	56	6.7
Mean	81	12.4	13.36	59	9.7
Deviation	(+33)	(-19)	(-38)	(-51)	(+471)
Corsican					
C3749	90	10.6	13.73	50	12.8
C3750	87	11.1	13.84	54	8.9
C3751	89	11.0	13.73	53	5.6
C3752	86	10.3	12.96	50	13.3
Mean	88	10.7	8.56	52	10.1
Deviation	(+44)	(-31)	(-39)	(-57)	(+494)

( )* Percentage deviation from the Leiria Routine control.

Half-sib Leiria and Landes

Thirty half-sib seed lots from plus trees collected in the Landes region as part of the French improvement program were supplied for testing in Western Australia. Two lots were included in trial XS12 (Fig. 7) and results of the remaining comparisons are expressed in Tables 13 to 17. The four trials concerned (XS11, YS08, YS09, YS10) sampled soil types and climatic variation at Gnangara, Yanchep and Mundaring plantations.

In trial XS11 (Table 12) all 14 Landes families tested were less than the Portuguese routine in height growth and only 2 families were equivalent in diameter growth at age 10 years. None of the other 13 Landes families tested in other trials (Tables 13, 14, 15, 17) achieved height and diameter growth equivalent to the Portuguese routine.

Three of eleven half-sib families collected from plus trees in Portugal, included in trial XS09, were superior to the routine control in height growth (Table 9). The remainder were comparable to the routine.

Inter-provenance Crosses

The family LSMA in Tables 13 to 16 was an open pollinated cross between ramets of locally selected Landes plus trees and a pollen mix from Leirian plus trees. This family is one of the rare cases in which a seed source associated with the Landaise origin matches, under local conditions, the vigour of the Portuguese routine. Parent selection and/or crossing may have improved the family vigour over that expected in imported Landes groups.

The significance of the dominance in vigour of the Leirian stock in inter-provenance crossing was tested in trials YS51, YS52, and YS53 in which 9 Leirian by

Leirian crosses (ExE) were compared with 9 Leirian by Landes crosses (ExL) and 8 Leirian by Corsican crosses (ExC). All parents were plus trees selected in local stands and the trial was repeated at Gnangara, Yanchep and Busselton. The first two sites are on the coastal plain adjacent to and north of Perth and are respectively, acid grey sands and limestone sands. Busselton, in the southern limit of sites available for *Pinus pinaster* afforestation in the State, is considerably cooler and less drought-prone.

The means in Table 30 for all families of similar crossing show the Leiria by Leiria cross is superior for height and diameter growth at each of the three sites. This growth advantage averages about 10 per cent better than the routine source but is slightly less than the result for the orchard seed which has exclusively superior plus trees as parents (Table 31).

The Portuguese dominance carried into the Leiria by Landes group is 4 to 6 per cent more than the routine for height and diameter growth. Several of the nine families within the Leiria by Landes group did not differ significantly from the best Leiria by Leiria family at each site.

The mean for the Leiria by Corsican group is equivalent to or slightly less than the routine.

The differences in vigour between the crossing groups is further defined in Figure 8. In this Figure the percentage of the families in each crossing group which are ranked within the top one third of the 28 families (i.e. ranked 1–9) for each trial are listed. For height and diameter measurements the Leiria by Leiria crosses dominate at all sites, except for early height growth at Gnangara.

Parents used in these crossings were among the best phenotypes selected from plantations in Western Australia. They are not, however, proven elite trees and several of the Leiria parents used have been culled from the seed orchard as a result of testing.

Relative improvements in the vigour of Landes and Corsican material through crossing with the Portuguese clearly depicts the genetic nature of attributes for vigour within the provenances.

Provenance Stability

The inter-provenance crossing trials YS51, YS52 and YS53 provide the opportunity to examine adaptability and stability of provenance groups over the range of local site conditions (Finlay and Wilkinson 1963; Bilbro and Ray 1976).

The diameter means for the 28 families, at age 9 years, plotted for each site (Fig. 5) show general superiority of the Portuguese influence (ExE) over that of the Landes (ExL) and Corsican (ExC), respectively.

Analysis of variance of the combined results found the site by family interaction to be significant and associated with some changes in the relative ranking of individual families with site (Fig. 5).

To further examine the contribution of provenance to the interaction the routine and orchard families were removed from the data which were re-analysed in a balanced design of 8 common crosses for each provenance group. The site by provenance interaction was highly significant (Tables 21 and 22). This was largely due to the Corsican provenance increasing diameter growth relative to that of the Portuguese provenance as site conditions altered.

Regressions for the mean of each provenance group (8 families) for each block (30 blocks), against the mean for all families in that block provided significantly different lines for the range of sites (Fig. 9). The Leiria by Leiria crosses ($b = 0.83$, $R^2 = 0.88$) tend to below average adaptability (Finlay and Wilkinson 1963) and the Leiria by Corsican crosses ($b = 1.20$, $R^2 = 0.94$) tend to above average adaptability over the range of sites. The Landes crosses ($b = 0.97$, $R^2 = 0.94$) have average adaptability. Very high correlation coefficients for the Landes by Leiria and the Corsican by Leiria data sets are indicative of high stability under the site conditions (Bilbro and Ray 1976). The stability of the Portuguese crosses, although still high, is lower than the others over the site range.

Discussion

The consistent and strong superiority of seed from the forest of Leiria over Landes, Corsican and Italian seed in respect to height, diameter and volume growth, demonstrated in these trials, supports preliminary conclusions (Hopkins 1960). The current series of trials is statistically controlled, cover the full range of sites available for afforestation and embrace a number of different seed collections. These requirements were not satisfied in earlier tests. The Tunisian provenance had not previously been tested locally.

No difference in vigour could be distinguished between the Portuguese routine and two provenances from the Spanish north-west Atlantic coast. Sweet and Thulin (1962) were also unable to separate Spanish Atlantic coastal provenances from those of the Portuguese and French Atlantic coast in trials in New Zealand. In trials on the Spanish north-west coast with 23 provenances from Spain, Portugal, France and Corsica, Rodriguez (1966) reported that the local provenances were superior to all in slenderness and favourable branching. They were also the best in height growth along with provenances from the French Landes region and the Portuguese Leirian forest. From a comparison of 22 provenances at age 7 years at Servanches in the Landes region, Alazard (1982) found that a Spanish seed lot, from Pontevedro, was slightly inferior in height growth to local provenances and Leirian provenances. The form of the Spanish, Landes and Leirian trees was similar.

The dominance of the Leirian in vigour over that of all other provenances of the species has been shown for Western Australia (Hopkins 1960), South Africa (Rycroft and Wicht 1947) and Greece (Matzyris 1982). Rodriguez (1966), in comparing 24 provenances on the north-west coast of Spain, did not separate the local

TABLE 30

Mean values for provenance crosses, the Leirian Routine and seed orchard seed at Gnangara (1), Yanchep (2) and Busselton (3). Heights are for 4.5 years of age, all other measurements at 9.5 years of age.

PROVENANCE GROUP	TRIAL LOCATION	MEAN HEIGHT (m)	MEAN DIAMETER (cm)	PERCENTAGE OF TREES WITH			
				STRAIGHT STEMS	NORMAL STEMS	FINE BRANCHES	FLAT BRANCHES
Leiria	1	3.8	15.5	45	33	69	28
x	2	3.6	14.4	55	45	75	24
Leiria	3	2.8	16.2	54	48	42	46
	Mean	(3.4)	(15.4)	(51)	(42)	(62)	(33)
Leiria	1	3.7	14.6	45	33	58	15
x	2	3.3	13.1	67	69	64	25
Landes	3	2.8	15.5	51	64	35	34
	Mean	(3.3)	(14.4)	(55)	(56)	(52)	(25)
Leiria	1	3.3	14.2	51	50	55	17
x	2	3.1	12.5	68	76	76	19
Corsican	3	2.7	15.6	73	72	39	47
	Mean	(3.0)	(14.1)	(70)	(66)	(64)	(31)
	1	3.6	14.3	22	22	63	16
Routine	2	3.2	12.7	48	48	68	24
	3	2.6	14.7	28	44	37	37
	Mean	(3.1)	(13.9)	(33)	(38)	(56)	(26)
Seed	1	3.8	15.2	64	46	72	18
Orchard	2	3.6	14.7	68	66	84	26
	3	2.9	16.3	62	51	40	34
	Mean	(3.5)	(15.4)	(65)	(54)	(65)	(26)

( ) Group Mean for the three locations.

TABLE 31

Variation from Routine seed lot values of composite means (3 locations) for provenance groups in trials YS51, YS52, YS53. Plus trees of Leiria, Landes and Corsican origin are coded E, L and C, respectively.

PROVENANCE GROUP	NO. FAMILIES	PERCENTAGE DEVIATION FROM ROUTINE SEED					
		HEIGHT (4.5YR)	DIAMETER (9.5YR)	STRAIGHT STEMS	NORMAL STEMS	FINE BRANCH	FLAT BRANCH
ExE	9	10	11	55	10	11	27
ExL	9	6	4	67	47	−7	−4
ExC	8	−3	1	112	74	14	19
Routine	Mix	0	0	0	0	0	0
Orchard	Mix	13	12	97	42	16	0

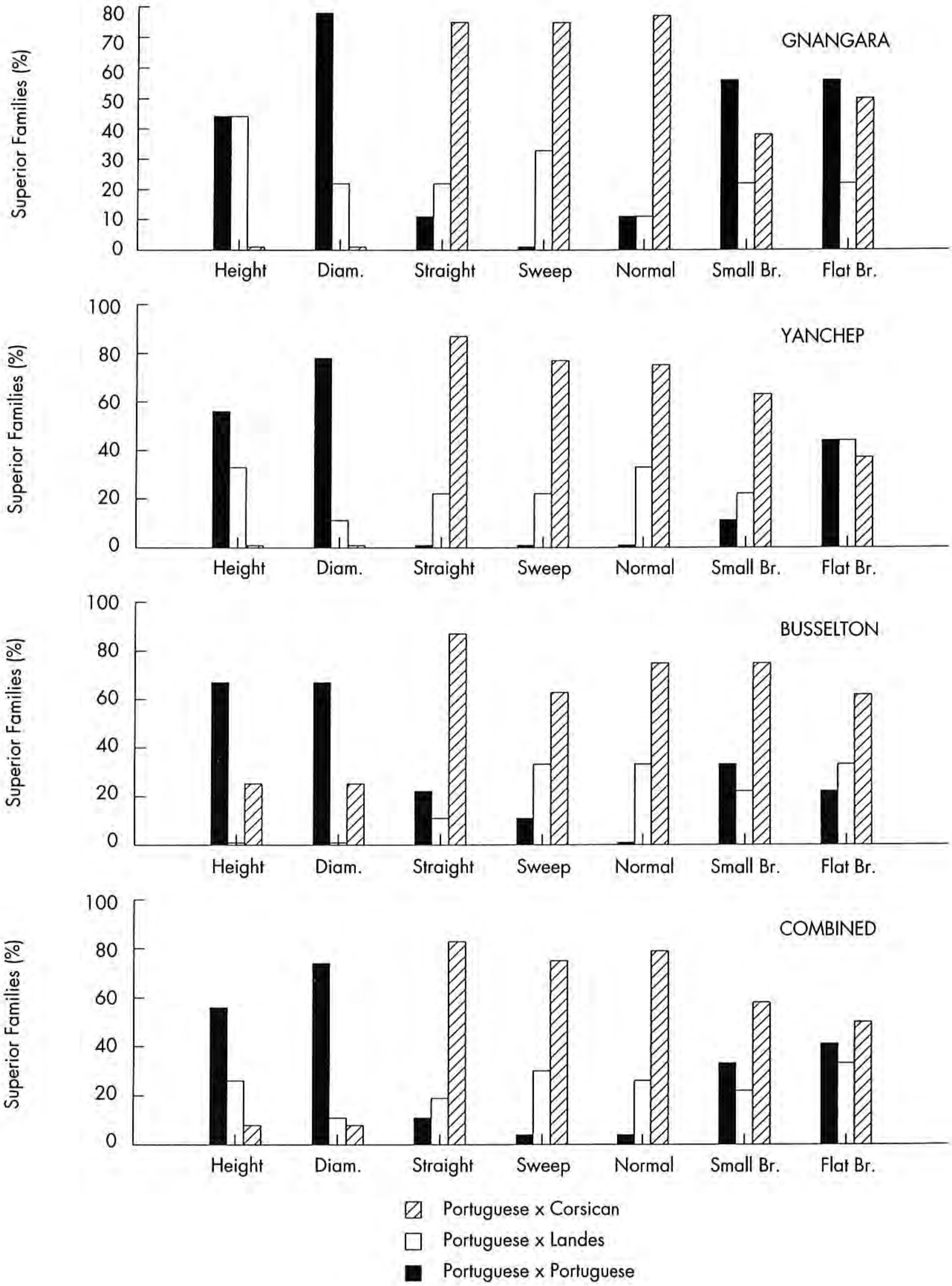

Figure 8. Proportion of inter-provenance crosses in trials YS51, YS52 and YS53 with superior growth and form and ranked within the best one third of all families.

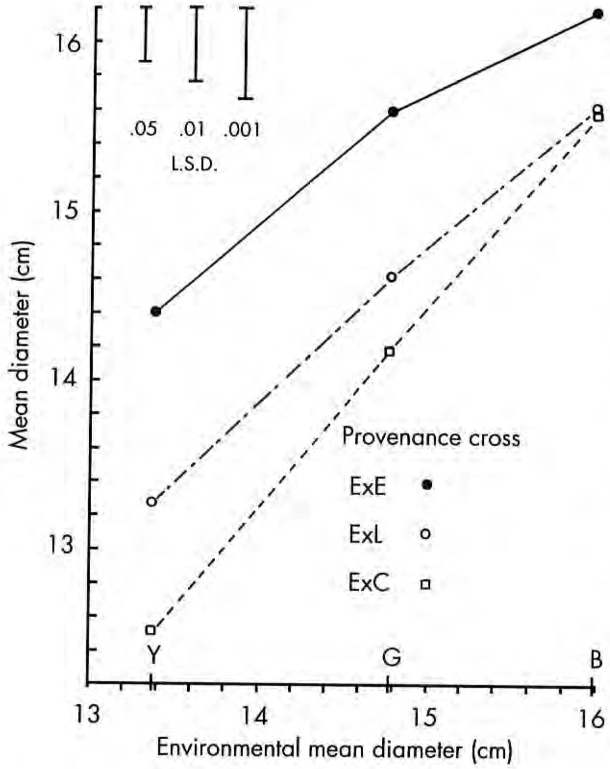

Figure 9. Interaction in diameter growth between provenance groups (8 families each) planted at Yanchep (Y), Gnangara (G) and Busselton (B). The Corsican influence (ExC) and to a lesser extent the Landes influence (ExL) is associated with better growth with the cooler, moister conditions progressing from Yanchep in the north to Busselton in the south.

source, the Landes, Leirian and an Esterel seed batch for top height and volume growth. Similarly, in New Zealand, Sweet and Thulin (1962) found that Landes and Leirian lots performed best of a wide range of provenances tested for height growth at age 5 years but were not significantly different from each other. They suggested there were no grounds to separate the Landes and Leirian groups on the basis of their results.

Illy (1966) and more recently Alazard (1982) have conclusively established the dominance in vigour of the native provenance over all others tested under Landes conditions. They attribute this largely to the relatively cooler nature of the sites and the inherent frost resistance of the local source. Reports on the performance of the species under recent severe winters in France (Alazard 1986; Chaperon 1986) identify the Landes as the most resistant and the Leirian provenance as the least resistant to frost damage. The Corsican is second in resistance with the Moroccan and the north coast Spanish following.

The inter-provenance crossings in the current trials clearly show an overall dominance in vigour for the Portuguese provenance (See Figs 5 and 9) while demonstrating some decline in adaptability and stability of diameter growth along a north-south gradient of increasingly cooler and wetter conditions (See Fig. 9, Table 22). Although the Portuguese provenance has superiority in vigour at this southern site, the data suggest that the Corsican and possibly the Landes genotypes are becoming more competitive under the cooler conditions.

Different performance of provenances in France (Alazard 1982) and New Zealand (Sweet and Thulin 1962) compared with that in Western Australia (Hopkins 1960), South Africa (Rycroft and Wicht 1947) and Greece (Matzyris 1982) may be attributed largely to adaptation of the Portuguese provenance to the warm, frost free conditions of these three regions.

DROUGHT RESISTANCE

During the development period of the current local provenance trials, the worst drought recorded for the area (1976–77) was common to the planting sites. The trial provenances were then aged approximately 10 years, embraced both favourable and drought-prone sites and provided ideal conditions to compare the drought resistance of provenances of the species.

Drought damage was assessable in trial XS12 (Table 8) and trial YS09 (Table 16) at Yanchep and trial XS11 (Table 12) at Gnangara. Results show superior drought resistance in the Leirian provenance to that in Landes and Corsican seed batches.

At the onset of the drought the Leiria routine in trial XS12 carried 80 per cent more stem volume and 20 per cent greater basal area than the Landes and Corsican stands and thus was more prone to drought. Yet it had only 2 per cent drought mortality compared with 10 per cent in the stands of smaller biomass and different origin (Table 8).

Results also show that selection and controlled crossing have favoured drought resistance over that in the non-selected, routine seed batches. This desirable trait, resulting from selecting dominant stems in local stands of Leirian origin, is accompanied by significant increases in vigour (Table 29). Also, in trial YS09 (Table 17) drought deaths in the half-sib Landes families varied from 0 to 10 per cent with the more vigorous locally selected Leiria by Landes cross (LSMA) suffering negligible drought damage. The results suggest there is scope for improvement in drought resistance within the Landes provenance.

Trial XS09 at Gnangara incorporated Spanish and Tunisian provenances. No mortality owing to the drought occurred in either of these provenances although surrounding trials were affected. The high survival rate could have been due to a favourable site but it is believed to be associated with a resistance like that of the Portuguese. This was partly confirmed by the non-replicated trial XR1 at Yanchep where performance between these three groups was similar, despite considerable mortality in the trial. The Italian provenance was almost destroyed in this trial (Table 10) and appears as the least resistant of all provenances tested.

No other quantitative comparisons of field drought resistance of provenances of *Pinus pinaster* exist but Destremau *et al.* (1982) note that the north African groups have high drought resistance. Hopkins (1971b) assessed the relative drought resistance of Portuguese, Landes, Tunisian and Corsican provenances from controlled studies of seedlings. The results, particularly from the viewpoint of improved resistance of selected material, are verified by the current field results.

Nguyen and Lamant (1989) report that Guyon (1980, 1982) and Sarrauste (1982) characterized different populations of *P. pinaster* according to shoot growth, needle water potential and biomass responses to drought. They found two provenances that differed greatly in drought sensitivity. Compared with the Tamjoute provenance from Morocco, the Landes provenance grew vigorously in well watered conditions, but relatively poorly when subjected to drought. Nguyen and Lamant (1989) found the Moroccan seedlings had a higher root elongation rate than the French seedlings. They also had a greater capacity for osmotic regulation, enabling them to maintain a greater water potential difference between root and soil, favouring water extraction under drying conditions.

The high drought resistance recorded in Western Australian trials supports a hypothesis of natural selection to favour the Leirian race on frost free, warm sites and the Landes race on frost prone, cooler sites.

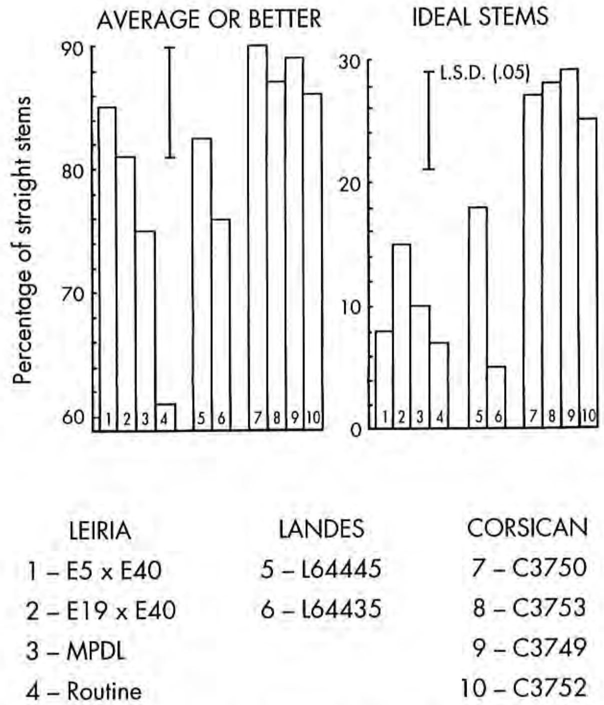

Figure 10. Frequencies of straight stems in provenances tested in trial XS12. Average or better refers to stems scored 1 to 3 on a 1 (best) to 5 (poorest) scale. Ideal stems were scored 1 and 2.

Stem Form

Straightness

Results for assessment of stem straightness in trial 3/65 (Tables 5 and 6) do not separate the two Portuguese provenances on the basis of proportion of leaning trees, straight stems, ramicorns and steepness of branching. Both were significantly inferior to the Corsican seed lot in all of these respects and to the Landes in all attributes except the proportion of trees with ramicorns. The Italian provenance had the least straight stems.

Stem straightness was also compared at stand age 7.5 years in trial XS12 (Fig. 10). The routine, MPDL half-sib and one Landes group were low in percentage of average and above average straight stems. One Landes group and all the Corsican groups were significantly superior to the routine. Within the Portuguese group the two improved full-sib families were also significantly straighter than the routine group (Fig. 10). This showed success in the plus tree selection process which aimed to favour stem straightness. In trial YS08 (Table 14) no difference in straightness could be found between the Landes half-sib families and the Portuguese routine. Again, in this trial, highly significant improvement (.01 level) in stem straightness over the routine batch resulted from selection and controlled crossing within the Portuguese provenance.

The heritable nature of stem straightness within provenances of the species is measured by crosses between Leiria, Landes and Corsican trees selected for straightness, with Leiria plus trees, in trials YS51, YS52, YS53. The Corsican crosses (ExC) were consistently superior in percentage of straight stems and non-forked normal stems at the three sites tested (Fig. 8, Table 30). The Landes crosses (ExL) were next in order of importance with the Leiria crosses (ExE) similar to the Landes in straightness but definitely inferior on the basis of apical dominance. Stem forking is a major defect in the provenance and this is borne out by the low percentage of non-forked stems obtained for both the routine Portuguese batch and the Leiria by Leiria cross in Tables 30 and 31. Results from the progeny of the Leirian seed orchard show a definite early improvement in the proportion of straight stems and apical dominance, through selection.

Differences in the inheritance of attributes for stem straightness are perhaps more clearly expressed in Figure 8. This Figure shows the percentage of families in each group of controlled crosses (ExE, ExL, ExC) occurring in the best families ranked for stem straightness and non-forked stems. For straightness the Corsican crosses have absolute superiority (83 per cent). There is little difference between the Leirian and Landes crosses (7 and 15 per cent) for straightness.

Seventy-nine per cent of the Corsican cross trees had a single leader compared with only 4 per cent for the Leirian crosses, again emphasizing the deficiency of the Leirian race in this respect.

These results show a remarkable improvement in the Leirian provenance through selection and controlled crossing. It may also be desirable to improve to the full potential for the species by hybridizing with Corsican select stems, a strategy recommended for improvement of the Landes group by Alazard (1982).

Branching

Steep, high angle branching is usually associated with the Atlantic race. Compared with the Corsican race, branching of the Landes and Leiria provenances is also considered to be relatively heavy and irregular.

In trial 3/65 (Table 6) the Portuguese provenances had significantly steeper branching than the Landes, Corsican and Italian provenances, which were inseparable in this respect. Results from trial YS08 (Table 14), however, showed no significant differences in branch angle between Landes, routine and selected families.

It can be seen from Table 14 that selection may alter the proportion of trees with low (flat) angled branching in the Portuguese population. Superior branch angle characteristics were recorded in only 2 of 14 full-sib families, and in 1 of the 14 branching was significantly steeper than in all other families in the trial.

Differences in branch thickness between the two Atlantic provenances are not so distinctive. In trial YS08 (Table 14) three of the four Landes families were not significantly different from the routine Portuguese in percentage of favourable small branched trees while the remaining family was poorer in this respect. Most full-sib families in the trial had better branch size characteristics than the routine seed source.

Inter-provenance crossing of Leiria by Leirian, Landes and Corsican groups in trials YS51, YS52, YS53 revealed considerable variation in the branch angle and branch thickness, with site (Table 30, Fig. 8). On the basis of average values for each provenance group shown in Table 31, the Leiria and Corsican have similar proportions of trees with acceptable flat branching with the Landes less acceptable. Comparison of the percentages of the families in each provenance group which occur in the top third of rankings for branch angle (Fig. 8) does not alter the situation. Similarly, the percentage of trees with fine branching alters somewhat with site. Results suggest that the Corsican crosses have a small advantage in the number of favourable stems.

Results for branch angle (Table 31) showed no improvement in the proportion of favourably branched stems in the orchard progeny over the unimproved routine. Improvement in branch thickness due to selection in the seed orchard population is considerable and the quality obtained approaches that of the Corsican crosses. Of the individual families which are the best or not significantly different to the best in branching, in the three trials, several are from crosses between Leirian plus trees (Tables 26 and 27). Improvement in branching could thus be obtained through tree selection within the provenance and there appears to be little merit in inter-provenance crossing to achieve this objective.

Discussion

Early studies in South Africa and Western Australia revealed the superiority of provenances from Corsica in stem straightness, absence of forks, regular, flat and fine branching and symmetrical crowns (Rycroft and Wicht 1947; Hopkins 1960). The outstanding form of this provenance has since been acknowledged from tests in France (Alazard 1982), Greece (Matzyris 1982), New Zealand (Sweet and Thulin 1962) and north Spain (Rodriguez 1966). It would appear that for decreasing ranking of stem straightness the Corsican provenance is followed first by provenances from Morocco and the Mediterranean coast of France and these are followed by the Atlantic coast and Genova-La Spezia provenances. The Luccan and some of the inland Spanish seed lots were inferior in stem straightness in New Zealand (Sweet and Thulin 1962). For percentage of trees judged acceptable for leader dominance in New Zealand, the Corsican, Italian and Moroccan seed lots had high values while the Atlantic coast provenances were less acceptable.

Experience in Western Australia and South Africa would generally place the Portuguese race slightly superior to the Landes in straightness. Sweet and Thulin (1962) were not able to separate these two geographic provenances on the basis of percentage of acceptable trees in trials in New Zealand. However, the high level of stem forking and ramicorn development is a major commercial defect in plantations of Portuguese origin (Rycroft and Wicht 1947; Hopkins 1960).

The Atlantic races have usually been attributed with long clean internodes and relatively high angle branches, with the Portuguese origin the most pronounced in these respects (Perry 1949; Hopkins 1960). Destremau *et al.* (1982) suggested that the Corsican race is usually uninodal, the Leirian race is occasionally multinodal and the Landes and Tunisian races are nearly always systematically multinodal. The present studies support these observations.

Flowering

Perry (1940, 1949) noted that the onset of flowering in provenances compared in the same plantation, under identical cultural conditions in Western Australia, was genetically controlled. The Portuguese race was the first to flower in early spring, followed by the French Landes and French Esterel and last of all the Corsican. This separation of approximately three weeks in onset of flowering between the Portuguese and Landes and Landes and Corsican races is also recorded for French provenance comparisons by Destremau *et al.* (1982).

Propensity for cone production has also been noted to vary with provenance. Prolific flowering of the Esterel and sparse flowering and cone production of Corsican seed lots noted by Perry is recorded for young plantation trials in New Zealand by Sweet and Thulin (1962). They also commented on the sparse flowering of trees of Moroccan origin. Rycroft and Wicht (1947) recorded sparse cone production of Corsican seed lots under South African conditions. Matzyris (1982) measured significant differences in the proportion of provenances bearing cones at the age of 9 years in trials in Greece. The most prolific provenances were Landes and Cevennes from France while the Corsican provenance produced the least cones at this age. Matzyris reported that the Portuguese provenance was also a low cone producer. Destremau *et al.* (1982) noted that the Tunisian race was a very precocious flower producer and flowered abundantly in the second year in the plantation. This fact was verified in trials of Tunisian plus trees in Western Australia.

Flowering Times

Results obtained within the improvement program quantify variation associated with flowering time and precocity in some provenances of *Pinus pinaster.* Differences are obviously due to genetic control within populations. The Portuguese and north-west Spanish provenances were the first to flower in spring, under Western Australian conditions, and the Corsican was the last to flower. The differences between these two extremes are distinct in the cases measured. The Landes provenance flowers in between these two extremes, is followed by the Tunisian, then the Italian and Corsican.

Fruitfulness

The Landes and Corsican provenances studied showed less precocity at age 5.5 years than Portuguese and Italian seed lots and had significantly less trees with cones at age 10.5 years.

Discussion

Results obtained are in accord with the general trends reported. They reveal, however, the great variation between genotypes within a population. Population means for a large sample should demonstrate that the Portuguese flowering is distinct from that of Landes with Corsican latest of the three. Variation within the species is in fact continuous and small or non representative samples could confuse the results.

The requirement for comprehensive sampling to overcome natural variability was also noted as essential for differentiation of terpene contents of provenances by Bernard-Dagan *et al.* (1971). They found that intra-specific variability of monoterpene contents of trees in the Landes district was not strong enough to be clearly shown with less than ten trees in a sample.

The importance of the representative nature of the seed lot in provenance comparisons was demonstrated in the field trials. The Landes provenance in trial 3/65 was similar in height growth and flowering characteristics to the Corsican (Tables 5 and 6). This is contrary to previous comparisons of these two provenances in Western Australia (Hopkins 1960). Examination of the flowering time for the Landes population used in trial 3/65 left little doubt that it has more akin to the Corsican group than to the general Landes group. Hence, although significant differences in precocity and stem straightness were associated with genetic origin in the trial, the provenance groups were not truly representative. Sampling to define the variation both within and between provenance areas is essential for realistic generalizations of differences between geographic groups of a species.

Results support reports of genetic control of precocity in provenances of *Pinus pinaster* (Sweet and Thulin 1962; Destremau *et al* 1982; Matziris 1982). The Landes and Corsican provenances studied showed less precocity at age 5.5 years than Portuguese and Italian seed lots and had significantly less trees with cones at age 10.5 years.

Knowledge of the variability in the time of flowering and fecundity between clones was important in designing the complement of grafts in seed orchards. Some clones within the populations under selection had a limited probability of crossing during the different optimum periods of receptivity. Other clones were prodigious cone producers and required less representation in stems in the orchard. Variation in the period of flowering and propensity for seed production are important to orchard balance. Fruitfulness also has a direct bearing on the unit cost of seed produced in an orchard.

Wood Properties

There is little information on the physical wood properties of the various provenances although considerable research has been carried out in Europe on resin properties and wood chemistry of trees and provenances (Bernard-Dagan *et al.* 1971).

Rycroft and Wicht (1947) measured wood density of sample discs from comparative trials in South Africa and found the Portuguese trees to have the highest density. Landes was next in order with Esterel, Corsican and Moroccan of lowest density. Generally the fastest growing trees yielded wood of highest density but the overall density range was small.

Nicholls *et al.* (1963) assessed wood properties of trees from early Western Australian provenance trials at Gnangara comparing provenances of Corsican, Landes, Esterel and Leirian origin. Basic density of Corsican wood was found to be markedly lower than the others. Differences in tracheid length were small. This study was followed (Nicholls 1967) with another using material from the Somerville provenance trial in Western Australia (Hopkins 1960). The Leirian provenance had the most favourable (least) grain deviation characteristics and again the Corsican was the poorest of the four provenances in this characteristic. Average tracheid length was similar in all provenances except in mature wood where the Esterel was significantly (.01 level) higher. Basic density of the Leiria was significantly higher than all other provenances.

Nicholls (1967) concluded that the trees of the Corsican provenance were inferior in wood quality and that the Leiria provenance offered the best potential for the improvement of wood characters in *Pinus pinaster*.

Perry measured spiral grain in 85 plus trees selected in Portugal and also took cores for analysis by the Commonwealth Scientific and Industrial Research Organisation (Perry and Hopkins 1967). Spiral grain varied from 0 to 6 degrees and density of mature wood ranged from 0.42 to 0.58 g/cc, within this selection (Nicholls 1968). The range of variation in basic density in both juvenile and mature wood is quite adequate to allow for improvement through breeding.

Racial Groupings

Provenance field trials in Western Australia (see Table 1) are of conventional field plot designs which effectively determine the significance of similarities or differences between individual attributes measured. For such designs normal analysis of variance (ANOVA) procedures assess the significance of the variation between treatments or families. Where significance is established for treatment variation, differences between the means of treatment attributes are assessed by least significant difference procedures.

The practice assesses accurately the superiority of families for height growth, stem straightness, time of flowering and one could ensure that parents employed in the breeding program were superior to a standard or control at a specified level of significance. This provides a reproducible selection differential. Selection becomes more complicated when breeding a number of traits concurrently and procedures such as combined index selection (Cotterill 1986), which integrate the family means and individual tree values for multiple traits into a single number or index, have been developed.

Similarly, from the point of defining provenance groups, it is desirable to be able to consider the commonality of grouping of the typical attributes, rather than the difference in one particular attribute. For this requirement the ANOVA is not necessarily satisfactory (Freeman 1973).

For trials 3/65 and XS12 which include a useful geographic range in families, discriminant analysis was used to confirm the importance of the differences of attributes measured in standard ANOVA procedures and to test the strength of expression of attributes that were assumed from results to be representative of major provenance groups.

Trial 3/65

Data obtained for each of the five provenances for pollen, cones, height, bends, multinodes, butt sweep, high angle branching, ramicorns and straightness in trial 3/65 (Tables 4, 5 and 6) were analysed by discriminant methods. All data except those for height were transformed to angle arcsin for the analysis.

The first analysis, termed Run 1, considered the five provenances Leiria R, Leiria 2, Landes, Italian and Corsican and all of the attributes mentioned above. Two of the four functions separated (Table 32) were highly significant and a territorial map was plotted for the centroids of each group, assuming all functions but the first two were zero (Fig. 11). The analysis correctly classified 92 per cent of the 25 actual groups. One Leiria R case was incorrectly classified as Leiria 2 and one Leiria 2 case was incorrectly classified as Leiria R; all other groups were correct.

Run 2 was similar to Run 1 but omitted height data, the most obvious difference measured between the groups and one in which the phenotypic expression is known to vary with climate of the test site (Alazard 1982). From Table 32 it can be seen that height was the major factor determining Function 2 in the scatterplot.

Run 2 correctly classified 84 per cent of the cases (Table 32) confusing one Leiria R for one Leiria 2, one Leiria 2 for one Leiria R, one Landes for Corsican and one Corsican for Landes. Again, three main groupings Leiria, Corsican and Landes and Italian were distinguished in which Leiria R and Leiria 2 and Landes and Corsica were not completely separated from each other (Fig. 11). The major contributors to Function 1 were the percentage of trees bearing cones in 1978 and percentage of trees with favourable branch angle. Percentage of straight stems was the major contributor to Function 2.

For Runs 3 and 4 the provenances were coded into three groups 1 – (Leiria R and Leiria 2), 2 (Landes and Corsican) and 3 (Italian). The analysis was highly significant and correctly grouped 100 per cent of the actual members. In Run 3 data for height, high angle branching and cones counted in 1968 were analysed. Again for Run 4 height data were omitted and groups were tested against cones in 1968, high angle branching, straightness, bends and ramicorns.

Trial XS12

Trial XS12 is a randomized block experiment with five replications. In ANOVA there were no significant block effects in measurements for height, diameter, average stem straightness (percentage 1, 2, 3 classes) and ideal stem straightness (percentage 1, 2).

In Run 1 the ten provenance families were analysed for the above mentioned attributes and two of the four canonical functions were highly significant (Table 33). Thirty-five of the 50 groups were placed correctly. Of those misplaced, five were Leirian placed in different Leirian groups, one Landes group was placed in the other Landes group and the other nine were Corsican placed in other Corsican groups. The scatter diagram in Figure 12 shows that although 70 per cent success was achieved in placing data groups into their correct family, there was virtually 100 per cent success in separating three distinct geographic races.

Run 2 used only five provenance groups – 1 (Portuguese Full-sib 1 + Full-sib 2) + 2 (Portuguese MPDL) + 3 (Portuguese Routine) + 4 (Landes 1 +

TABLE 32

Results from canonical discriminant analyses of measured attributes in trial 3/65.

CANONICAL DISCRIMINANT FUNCTIONS

	RUN 1				RUN 2		RUN 3	
Function	1	2	3	4	1	2	1	2
Eigenvalue	135	20.5	2.46	0.31	76.4	3.25	49.5	1.01
Percent of Variance	85.4	12.9	1.6	0.2	95.4	4.1	98.0	2.0
Cumulative Percent	85.4	98.3	99.8	100	95.4	99.5	98.0	100
Canonical Correlation	1.00	0.98	0.84	0.48	0.99	0.88	0.99	0.71
Wilks' Lambda	0.00	0.01	0.22	0.77	0.00	0.16	0.01	0.50
Degrees of Freedom	36	24	14	6	20	12	6	2
Significance	0.00	0.00	0.03	0.60	0.00	0.00	0.00	0.00
Provenance Groups		5			5		3	

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

FUNCTION	1	2	3	4	1	2	1	2
Pollen 69	0.94	−1.18						
Cones 68	1.63	−0.02			1.28	0.18	1.11	−0.43
Height 75	−1.89	2.83					0.58	0.88
Bends 75	−0.27	0.59	Not		0.18	−0.30		
Multinode 75	0.14	0.21						
High Angle 75	1.10	0.21			0.79	0.18	0.89	0.18
Ramicorns 75	0.94	−0.64	Relevant		0.61	0.23		
Straightness 75	−0.73	0.21			−0.51	0.94		
Cones 75	1.59	−1.53						
Percentage of Groups Correctly Classified		92%			84%		100%	

Landes 2) + 5 (Corsican 1 + Corsican 2 + Corsican 3 + Corsican 4).

The analysis for the first two canonical functions was again highly significant, differentiating mainly in coefficients for height in Function 1 and for d.b.h.o.b. and straightness in Function 2. All but six of fifty cases were correctly classified. Of these six, all were Leirian misplaced into alternative Leirian cases, generally from full-sib and routine into the half-sib (MPDL). The scatter diagram in Figure 12 depicts three distinct racial groups.

Run 3 grouped the provenance family data into three groups, Leiria, Landes and Corsican. The analysis was highly significant and correct grouping was achieved for 98 per cent of cases, the exception being the one Corsican case that is actually closer to the centroid for the Landes data (Fig. 12).

Discussion

Discriminant analysis assists in the interpretation of provenance variation in four aspects:

1. It provides an alternative method to evaluate the utility of the classification procedures used for assessment of attributes of form and flowering.
2. A further appreciation is obtained of the factors or attributes which are strongest in separating the provenances.
3. Further to 2, it shows that the geographic groupings are valid (in trial 3/65) independent of height data which may vary in expression in different countries (Sweet and Thulin 1962; Alazard 1982).
4. It substantiates the extent to which measured attributes relate to the original families, i.e. inheritance.

Results, which employ different provenance groups in each trial, substantiate the basis for identified geographic races (Destremau *et al.* 1982). The Portuguese, Italian, Corsican and Landes appear as distinct groups. Even in the analysis for trial 3/65 where the Landes and Corsican and Leiria were grouped to show close relationships, in the initial Run 1 the Landes and Corsican groups were correctly separated and only one in five of the cases in each of the

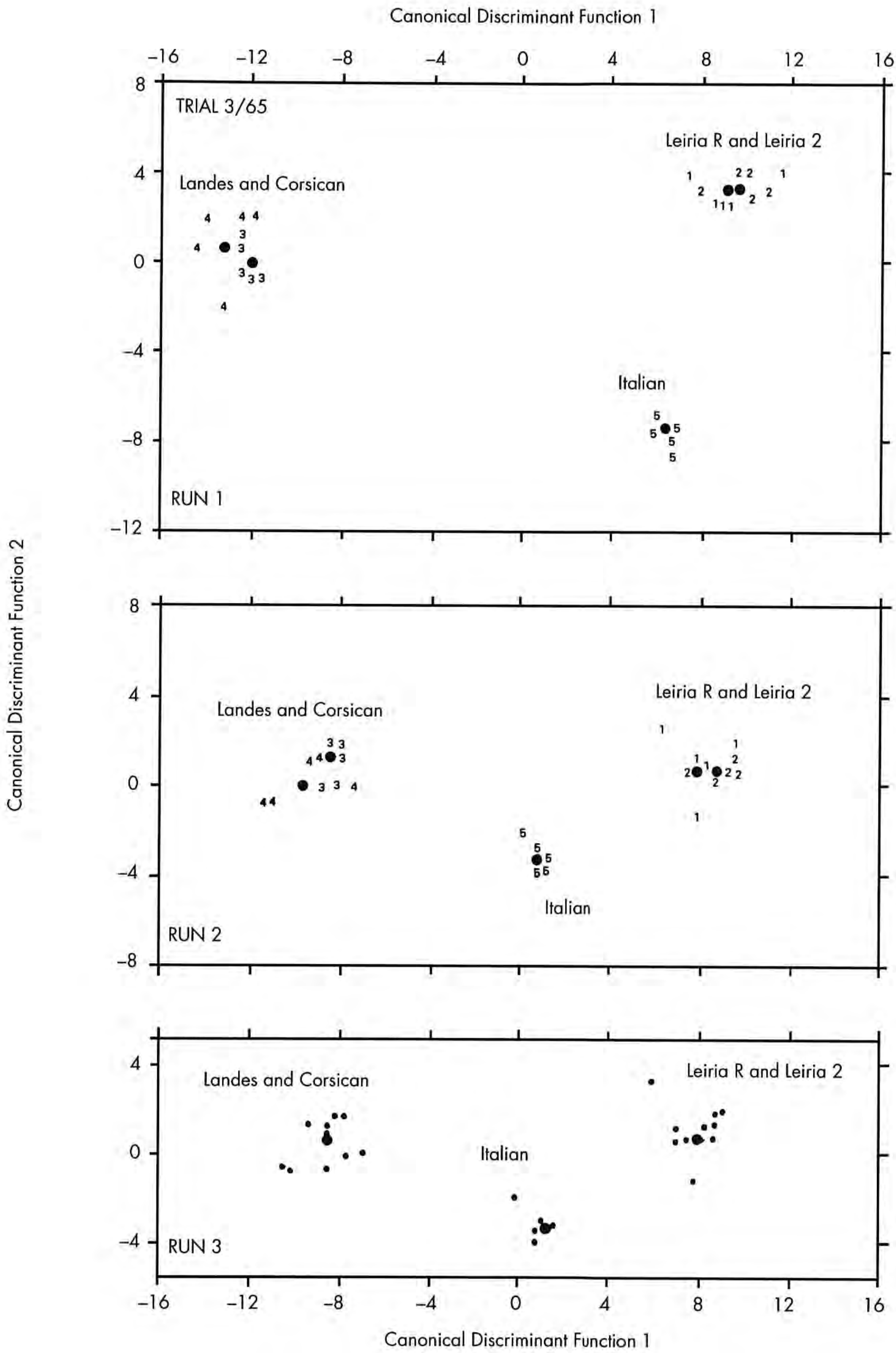

Figure 11. Discriminant analysis of field data measured in trial 3/65 showing clear separation of provenance groups.

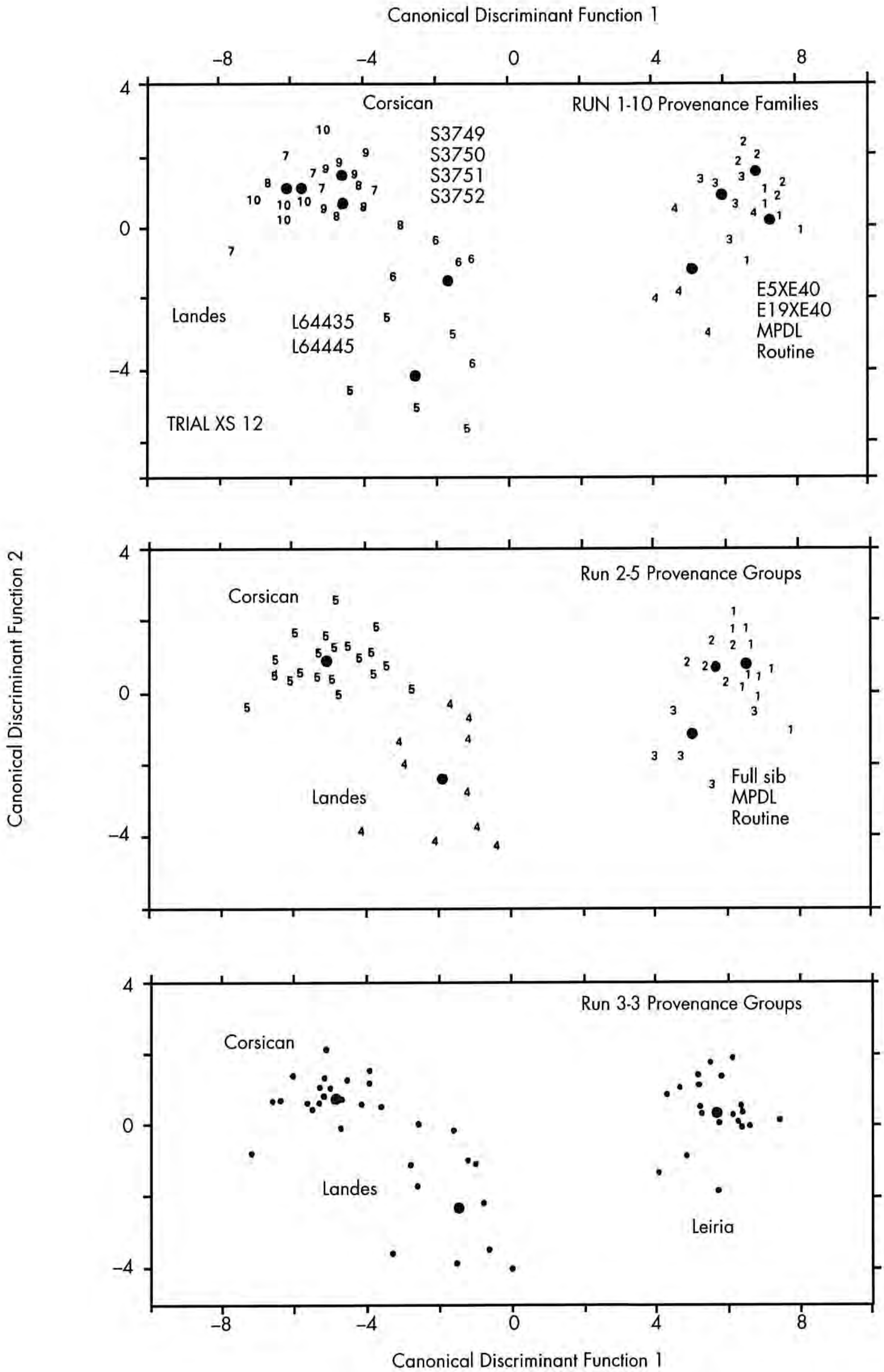

Figure 12. Discriminant analysis of field data measured in trial XS12 showing separation of provenance groups.

TABLE 33

Results from discriminant analyses of measured attributes in trial XS12.

CANONICAL DISCRIMINANT FUNCTIONS

	RUN 1				RUN 2		RUN 3	
Function	1	2	3	4	1	2	1	2
Eigenvalue	35.6	3.71	0.36	0.18	28.5	2.01	24.7	1.41
Percent of Variance	89.4	9.3	0.9	0.5	92.6	6.5	94.6	5.4
Cumulative Percent	89.4	98.7	99.6	100	92.6	99.1	94.6	100
Canonical Correlation	0.99	0.89	0.51	0.39	0.98	0.82	0.98	0.77
Wilks Lambda	0.00	0.13	0.63	0.85	0.01	0.26	0.02	0.42
Degrees of Freedom	36	24	14	6	16	9	8	3
Significance Level	0.00	0.00	0.14	0.33	0.00	0.00	0.00	0.00
Provenance Groups		10			5		3	

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENT

FUNCTION	1	2	3	4	1	2	1	2
Height	0.89	−0.46	Not		0.88	−0.51	0.99	−0.54
Dbhob	0.27	1.05			0.26	0.99	0.15	1.02
Straightness 1,2,3	−0.17	0.27	Relevant		−0.19	0.36	−0.43	−0.00
Straightness 1,2	0.00	0.86			−0.12	0.58	−0.15	0.67
Percentage of Groups Correctly classified		70%			88%		98%	

Leiria R and Leiria 2 data were confused with the adjacent provenance. This common grouping supports the similarities found for individual traits by the ANOVA procedures and provides a desirable integration of the ANOVA results.

It has previously been noted that the Landes family (S2865) used in trial 3/65 was more akin to the Corsican norm for time of flowering, low vigour and high percentage of straight stems (Tables 4, 5 and 6). This observation is supported by the present analysis in the close affinity of the Landes bulk provenance with the Corsican, demonstrated in Figure 11.

The tight grouping of the Leirian routine, half-sib and full-sib families represents a tree type typical of seed from Leiria and the refinement of major variabilities within the population.

Within the present study, discriminant analysis provides a clear illustration of the unique and heritable characteristics of geographic races within the species.

Adequacy of Studies

Bernard-Dagan *et al.* (1971) and Sweet and Thulin (1962) stress the need for provenance sampling to be fully representative and statistically identifiable with the population it is required to depict. Current studies support this and suggest that trials which do not permit intra-provenance as well as inter-racial comparisons are of limited value in commenting on geographic genotypes.

Trial XS12 in the local studies, although relatively small, was ideal in allowing inter-and intra-provenance comparisons. Most other trials had satisfactory representation within a geographic group and reliability in sampling for seed collection. Trial 3/65, on the other hand, was not replicated within provenance groups except for the Portuguese and provided uncharacteristic results for vigour, branching, straightness and fecundity for the Landes provenance. The deficiency demonstrates clearly the wide variation present within any geographic grouping.

Many trials designed for forestry purposes are also biased in that they sample specific phenotypic characters of commercial importance i.e. dominant height growth, diameter growth, stem straightness (Rycroft and Wicht 1947). Both the sampling procedure and the assessment procedure of the trials carried out may fall short of the requirements of a geneticist or physiologist. Despite these possible shortcomings, consistent and distinctive attributes are associated with provenances from different geographic areas. Association of the phenotypic variation of characters of commercial interest to forestry with a genetic imprint with geographic identity is proven.

Current studies reveal the continuous nature of variation within a species and the actual geographic ranges which could be associated with the dominant transmission of an attribute is still to be defined. To a degree, the extent of grouping or classification is a matter of convenience depending on the attributes measured, accuracy of measurement, range of variation studied and grouping or analysis procedure employed.

Knowledge obtained from a wide range of field trials and literature reports satisfactorily delineate populations for practical breeding programs. Characters of importance within each provenance can be separated and developed within breeding programs.

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