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Geographic Variation and Early Growth in South-eastern Semi-arid Australia of Pinus halepensis Mill. and the P. brutia Ten. Species Complex

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Introduction

A century of investigation has clearly indicated that species from the vicinity of the Mediterranean or California are the most successful conifers in the relatively dry winter-rainfall areas in the southern parts of Australia (HALL 1951). In these regions most coniferous plantations consist of exotic species of the gerius Pinus.

In addition to Pinus radiata D. DON, the most widely planted introduced species, Pinus pinaster AIT. and P. nigra ARN. have been successfully grown in Australia. To the same sub-section of the genus as the two last-mentioned species (sub-section Sylvestres LOUD.) belongs the species complex of Pinus halepensis MILL./P. brutia TEN. (CRITCHFIELD and LITTLE 1969). Species in this group are exceptionally resistant to adverse climatic conditions. (For description of species see e.g. ALLEGRI 1973, BEISSNER and FITSCHEN 1930, DEBAZAK and TOMASSONE 1965, MIROV 1955 and 1967, MIROV et al. 1966, NAHAL 1962 and SAFAROV 1970. For deccription of the species as exotics in Australia see BROWN and HALL 1968 and HALL et al. 1972).

In 1967 the Forest Research Institute[1]) of the Forestry and Timber Bureau acquired seed for an arboretum in the semi-arid region of south-eastern Australia in which a number of species and provenances might be screened to determine their value as plantation, shelterbelt, soil stabilisation and amenity species. The seed received included material from throughout the natural range of Pinus halepensis and P. brutia, as well as samples of the closely-related species of P. *eldarica* MEDW., P. pithyusa STEVEN and P. pithyusa STEVEN var. *stankewiczii* (SUK.) FOM. Little infornation is available on the composition of the seedlots except for their geographic location (Tables 1 and 2).

[1]) Now the Division of Forest Research, CSIRO.

Material and Methods

A total of 42 provenances of Pinus halepensis, 18 provenances of P. brutia, 2 provenances of P. eldarica and 2 provenances of P. pithyusa were raised in polythene tubes at the Forest Research Institute, Canberra.

As there are no obvious potentially important gaps in the set of sample the provenances can be considered to represent the natural distribution of the species fairly well, athough the number of provenances from any specific area does not necessarily reflect the extent and importance of the species in that area (*Figure* 1).

Field trials were established in June 1968 20 km west of Jerilderie, New South Wales (35° 22' S, 145° 44' E, elevation approx. 100 metres above sea level) on a site representative of the semi-arid region of south-eastern Australia.

Average annual rainfall at Jerilderie (1887—1975) is 390 mm (Table 3). The dry season, during which the actual evapotranspiration falls below the potential evapotrans-

TABLE 1. — List of provenances: *Pinus halepensis* Mill.

Provenance no.	Country	North lat.	East long.	Altitude (m)
1	France	43°31'	5°00'	130
2	Italy	42°34'	12°38'	400
3	"	41°54'	16°00'	150-300
4	"	40°35'	17°07'	15
5	Spain (Balearic Is.)	39°30'	3°00'	-
6	Spain	38°00'	1°00'(2)	-
7	Greece	37°42'	21°23'	120-140
8	Tunisia	36°53'	10°47'	50
9	"	36°48'	10°35'	200
10	"	36°42'	10°40'	200
11	"	36°32'	9°32'	300
12	"	36°32'	10°17'	200
13	"	36°23'	9°20'	700
14	"	36°22'	8°25'	800
15	"	36°22'	10°05'	400
16	"	36°22'	10°25'	100
17	"	36°17'	9°44'	300
18	"	36°16'	8°37'	400
19	"	36°15'	9°58'	500
20	"	36°12'	8°30'	900
21(1)	"	36°02'	9°35'	800
22	"	35°36'	9°35'	700
23	"	35°52'	9°25'	1000
24	"	35°48'	9°45'	300
25	"	35°28'	8°37'	1100
26	"	35°20'	8°50'	1300
27	"	35°20'	9°12'	800
28	"	35°12'	8°42'	1700
29	"	35°08'	9°08'	600
30	"	35°07'	8°30'	400
31	Malta	35°55'	14°30'	-
32	Lebanon	34°00'	36°00'	300
33	Israel	32°44'	35°00'	400
34	Morocco	31°30'	7°00'(2)	1200
35	Jordan	31°32'	35°06'	1000
36	Algeria	35°44'	7°22'	1100
37	"	34°50'	0°50'(2)	1200
38	"	34°52'	1°20'(2)	900
39	"	35°22'	8°25'	1400
40	"	34°39'	3°14'	-
41	Turkey	37°09'	35°33'	300
42	Greece	39°45'	23°30'	500

(1) Not planted at Jerilderie
(2) Degrees west

TABLE 2. — List of provenances: *Pinus brutia* Ten., *P. eldarica* Medw. and *P. pithyusa* Steven

Provenance no.	Species	Country	North lat.	East long.	Altitude (m)
1	*Pinus pithyusa*	USSR	45°00'	35°00'	<50
2	*Pinus pithyusa* var. *stankewiczii*	"	44°30'	34°09'	<50
3	*Pinus brutia*	Turkey	37°30'	30°30'	700
4	" "	Iraq	37°00'	43°25'	900
5	" "	Greece (Rhodes)	36°26'	28°18'	200
6	" "	Cyprus	35°17'	33°00'	500
7	" "	"	35°00'	33°00'	500-1000
8	" "	"	34°57'	33°14'	500-1000
9	*Pinus eldarica*	Iran	34°40'	60°20'	1300
10	*Pinus brutia*	Lebanon	34°00'	36°00'	400
11	" "	Israel ex Greece	-	-	-
12	" "	Turkey	37°44'	30°17'	6-700
13	" "	"	36°05'	36°03'	4-700
14	" "	"	36°12'	29°38'	8-1000
15	" "	"	36°57'	28°40'	50
16	" "	"	36°37'	29°08'	700
17	" "	"	37°45'	36°40'	800-1100
18	" "	"	41°34'	35°56'	<300
19	" "	"	37°21'	28°25'	800
20	" "	Greece (Rhodes)	36°00'	27°00'	400
21	" "	" (Thasos)	40°42'	25°00'	600
22	*Pinus eldarica*	Iran	35°48'	50°58'	1300

piration extends over a period of 7 months; however, part of the water surplus from the 5 wet months will generally be retained in the soil and will be available for growth later in the season (*Figure 2*). The site is flat with no rocks or ash heaps, the soils are mixed red-brown earths of fine, sandy texture, and brown, heavy soils with a high clay-content. The brown soils occur on the eastern side of the site and plots in this area are subject to flooding after heavy rain.

Bands of heavy, cracking soils run through the trial area in an east-west direction causing variation within blocks especially in the *P. halepensis* trial. The original vegetation was open woodland of *Callitris glauca* R. Br. ex R. T. Bak. et H. G. Sm., *Eucalyptus woollsiana* R. T. Bak. and *Casuarina cristata* Miq.; before planting this was completely cleared and a cultivation method of ripping and ridging, adapted from the *Methode Steppique*, was used (see Catinot 1967).

The seedlings were planted at 12 × 8 ft (3.6 × 2.4 m) in plots of 9 trees. The two adjacent trials of *P. halepensis* and *P. brutia* were arranged in randomised complete blocks with 5 replications. The closely releated species of *Pinus brutia, P. eldarica* and *P. pithyusa* were for practical reasons planted into the same trial. When reference is not made to a specific provenance *Pinus brutia* should therefore be unterstood to comprise all three species.

Before and during the nursery stage the following characteristics were assessed:

(1) seed weight, length and width;
(2) germination percentage;
(3) germination rate, i.e. number of days required for 75% of the viable seed to germinate at 20—30° C;
(4) cotyledon numbers, scored for 50 seedlings per provenance soon after germination;
(5) hypocotyl and cotyledon lengths, measured for 25 dominant seedlings in each provenance;
(6) 1-year heights, measured for 20 dominant seedlings in each provenance.

In the field, survival and height of trees were assessed in August 1969, May 1970, April 1972 and November 1974. In 1974 diameters of trees were also measured, and a visual assessment was made on stem straightness and branching habit. Height was measured from the ground to the tip of the leader using height sticks, diameter at 1.3 metres was measured using diameter tapes.

Volumes were calculated using the formula:

$$\text{height} \times \pi \times 1/3 \left(\frac{\text{diameter}}{2}\right)^2$$

The figures for volume should be considered as indicative only as the use of diameter at 1.3 m in the formula exaggerates differences between tall and short trees. The parameter was therefore omitted from the multivariate analyses.

Values for survival were transformed by arcsin $\sqrt{\text{proportion survival}}$.

Experimental results were computed on the basis of plot and provenance means.

Growth and survival data were subjected to analyses of variance, and data on seed origin (latitude, longitude and altitude) and seed and seedling characteristics (1 to 6 above plus growth and survival in the field) were compared using correlation coefficients. Principal component analyses for seed and seedling characteristics were made on the correlation matrices, followed by rotation of the component axes. The relationship between geographic origin and biological characteristics was examined by canonical analyses.

In the principal component analysis, relationships among the observed variables are examined transforming the old correlated variates into uncorrelated and independent new components, normally resulting in a reduction in the dimensions of variation. Linear functions (axes) which are mutually independent and which have the largest possible variance are then located; the components are thus based on the principal axes about which the variance is at its maximum (Steel and Torrie 1960; Jeffers 1962).

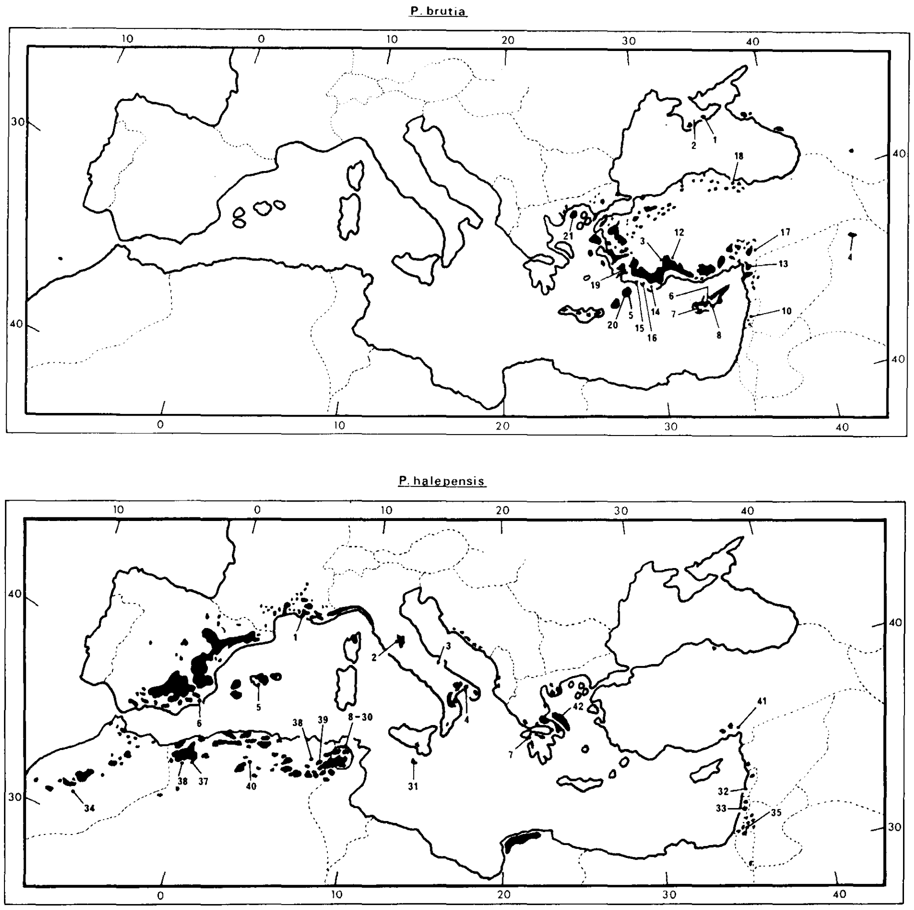

Figure 1. — Natural distribution of *Pinus halepensis* and *P. brutia* (shaded) and approximate location of provenances included in the study[1]). (Range map from CRITCHFIELD and LITTLE, 1966)

[1]) Location of Iranian land races (provenances 9 and 22) of *P. brutia* outside range map; exact location of provenance 11 of *P. brutia* not known.

TABLE 3. — Average monthly rainfall (mm) at the McCaughey Memorial Institute, Jerilderie (35°22' S, 145°44' E)(1)

Month	1968	1969	1970	1971	1972	1973	1974	7 yr mean	88 yr mean
January	17.0	14.5	55.6	10.9	20.3	39.9	254.8	59.0	24.8
February	0.0	97.0	13.2	27.9	28.2	109.5	43.9	45.7	25.8
March	20.8	74.8	45.7	31.2	7.4	8.9	8.9	28.2	32.3
April	38.0	46.0	67.3	36.8	25.9	108.0	109.0	61.6	33.0
May	95.3	34.5	11.2	11.3	7.4	30.2	144.8	47.8	38.3
June	44.5	9.8	23.4	18.5	7.4	64.0	4.1	24.5	40.8
July	42.5	55.8	13.7	37.9	10.9	32.3	58.2	35.9	32.0
August	22.8	26.8	62.0	21.3	50.0	108.2	56.9	49.7	36.5
September	9.8	25.5	109.0	13.7	4.3	31.0	53.6	35.3	32.3
October	31.8	10.3	6.9	6.4	10.2	128.3	67.8	37.4	40.0
November	13.8	28.3	31.0	109.2	16.8	33.0	26.4	36.9	27.3
December	39.5	11.0	18.8	38.1	0.0	52.8	6.1	23.8	26.3
Total	375.8	434.3	457.8	363.3	188.8	746.1	834.5	485.8	389.4

(1) By courtesy of Mr G.J. Wright, Manager, McCaughey Memorial Institute

The canonical model analyses the extent and nature of inter-relationships of two sets of measurements (in this case geographic origin and biological characteristics) selecting linear functions (axes) that have maximum covariances between the two sets, subject to restrictions of orthogonality (COOLEY and LOHNES 1972). A canonical score, calculated for each observation (in this case for provenance) and for each axis is compared with each input variable in turn using simple and partial correlation coefficients. Simple coefficients are calculated considering each input variable separately, whereas interrelationships between variables are taken into account in the partial coefficients.

Results

Survival. Survival in August 1969, one year after planting, was 74% (range among provenances 54—89%) for *P.*

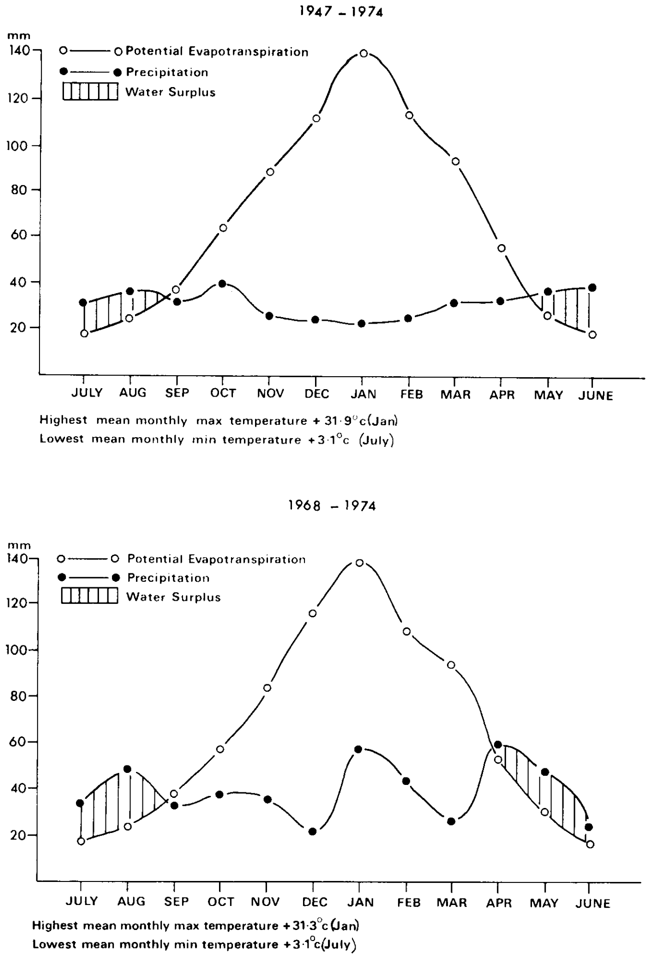

Figure 2. — Precipitation and potential evapotranspiration at Jerilderie[1]).

[1]) Potential evaporation was calculated according to THORNTHWAITE and MATHER (1957).

halepensis and 87% (range 33—100%) for *P. brutia*. Very highly significant differences in survival were found throughout the measurements between blocks whereas differences between provenances were non-significant.

Height. In *P. halepensis,* very highly significant differences for all height measurements were found between blocks, differences between provenances varied from significant to highly significant *(Table 4).* In *P. brutia* the significant differences found between blocks in 1969, 1970 and 1972 had disappeared by the time of the latest measurement (1974). Significant to very highly significant differences in height were found between provenances in the first two measurements (1969 and 1970) *(Table 5).*

Diameter and Volume. In *P. halepensis* the variation in diameter between blocks was significant at the 0.1% level and between provenances at the 5% level, i.e. a result similar to that obtained for the height measurements. Differences in volume were significant at the 0.1% level both between blocks and between provenances *(Table 4).*

In *P. brutia* diameter differed significantly between provenances but volume did not. Neither diameter nor height differed between blocks *(Table 5).*

Mean heights and diameters and ranking of provenances are shown in *Table 6.*

Form of trees. On the whole, trees of the *P. brutia* group had a straighter bole, finer branches and larger branch angles than those of *P. halepensis.* Provenances 9 and 22,

TABLE 4. — Analysis of variance : Pinus halepensis, Jerilderie

Height

Source of variation	Degrees of freedom	Mean square			
	1969-74	1969	1970	1972	1974
Blocks	4	16.4***	1129.6***	6473.6***	451.6***
Provenances	40	4.6**	139.8*	865.2**	42.6*
Error	155	2.1	89.8	434.4	27.4

Diameter and Volume

(1974)

Source of variation	Degrees of freedom	Mean square	
	Diam.& vol.	Diam.	Vol.
Blocks	4	26.9***	3.1***
Provenances	40	2.6*	1.4***
Error	155	1.6	0.7

* Significant at the 5% level
** Significant at the 1% level
*** Significant at the 0.1% level

TABLE 5.— Analysis of variance : Pinus brutia, Jerilderie

Height

Source of variation	Degrees of freedom	Mean square			
	1969-74	1969	1970	1972	1974
Blocks	4	2.5*	344.4***	930.0***	17.0 NS
Provenances	21	5.6**	96.8***	268.7 NS	17.5 NS
Error	84	0.7	36.3	193.2	11.1

Diameter and Volume

(1974)

Source of variation	Degrees of freedom	Mean square	
	Diam.& vol.	Diam.	Vol.
Blocks	4	1.0 NS	1.2 NS
Provenances	21	1.4*	0.8 NS
Error	84	0.8	0.5

* Significant at the 5% level
** Significant at the 1% level
*** Significant at the 0.1% level
NS Non significant

P. eldarica, are exceptionally good in regard to stem straightness and branching. *P. pithyusa* (provenance 1) has a fine, regular crown and attractive branching habit. Other provenances of better than average form within the *P. brutia* complex include provenances 2 *(P. pithyusa* var. *stankewiczii,* USSR), 6 and 7 (Cyprus), and 12, 17, 18 and 19 (Turkey).

In *P. halepensis,* provenance 41 (Turkey) is exceptionally good with a straight stem, regular crown, and fine branching. Provenance 42 (Greece), has a remarkably poor stem form. Among provenances with good form are 2, 3 and 4 (Italy), 10, 20, 28 and 30 (Tunisia) and 34 Morocco).

Correlations. The correlation matrices are shown in *Tables 7* and *8.*

In *P. halepensis,* a statistically significant positive correlation was found between seed weight, width and length, and between all these characteristics and altitude (elevation of seed source). The seed characters were also positively

TABLE 6.— *P. halepensis* and *P. brutia*: mean heights and diameters and ranking of provenances

P. halepensis

1969 Mean height (cm)	1969 Provenance no.	1970 Mean height (cm)	1970 Provenance no.	1972 Mean height (cm)	1972 Provenance no.	1974 Mean height (cm)	1974 Provenance no.	1974 Mean diam. (cm)	1974 Provenance no.
36.6	18	66.6	4	133	4	303	4	4.2	42
35.8	41	64.2	41	127	42	303	42	4.0	4
35.3	14	63.1	14	124	41	292	27	3.7	27
35.1	6	62.0	6	117	6	289	41	3.5	40
35.1	31	61.7	3	116	14	288	40	3.4	41
35.1	4	59.7	18	113	3	286	14	3.4	14
34.5	17	58.0	42	111	27	285	17	3.3	20
34.3	16	57.5	7	111	18	279	18	3.2	28
34.3	3	57.3	31	110	40	274	13	3.1	6
34.3	24	56.6	20	108	28	273	6	3.1	18
33.3	7	56.3	35	107	20	271	28	3.1	35
33.3	35	55.5	40	107	17	270	37	3.0	3
32.8	33	55.3	27	106	35	269	35	3.0	37
32.5	40	55.1	5	106	37	267	16	3.0	17
32.3	32	54.9	33	105	13	266	20	2.8	34
32.3	10	54.7	34	104	16	264	3	2.8	13
31.8	34	54.7	28	103	7	261	33	2.6	33
31.8	13	54.6	37	103	34	255	24	2.5	5
31.5	11	54.6	16	102	24	247	34	2.5	16
31.5	36	54.4	10	101	33	246	7	2.4	24
31.2	20	54.2	13	101	5	243	31	2.4	7
31.2	25	54.0	24	100	31	242	25	2.3	1
31.2	22	53.7	36	97	32	241	9	2.3	31
30.7	28	53.4	22	96	25	240	23	2.3	36
30.7	23	52.6	25	95	23	240	22	2.2	25
30.7	37	51.8	17	95	22	240	19	2.1	32
30.5	12	50.6	23	94	36	239	1	2.1	23
30.2	27	50.3	30	93	1	238	5	2.1	19
30.2	42	50.2	2	93	19	234	36	2.0	22
30.2	30	50.1	11	93	9	232	8	2.0	8
30.0	5	49.8	32	92	10	229	32	2.0	2
30.0	38	49.5	26	92	39	227	39	2.0	9
30.0	8	48.8	39	92	2	223	2	2.0	39
29.7	15	48.2	5	90	8	222	30	2.0	30
29.7	19	47.9	9	88	30	220	10	1.9	10
29.7	26	47.7	38	86	26	212	38	1.7	38
29.2	29	47.1	8	84	38	211	12	1.6	26
28.7	9	46.4	1	83	29	210	29	1.6	29
28.7	2	45.8	12	83	12	209	26	1.5	12
28.0	39	45.7	19	80	11	206	11	1.4	15
27.4	1	44.8	29	73	15	187	15	1.4	11
mean 31.2		mean 53.7		mean 100		mean 250		mean 2.5	
LSD (5%) 1.8		LSD (5%) 11.8		LSD (5%) 26		LSD (5%) 7		LSD (5%) 1.6	

P. brutia

1969 Mean height (cm)	1969 Provenance no.	1970 Mean height (cm)	1970 Provenance no.	1972 Mean height (cm)	1972 Provenance no.	1974 Mean height (cm)	1974 Provenance no.	1974 Mean diam. (cm)	1974 Provenance no.
30.7	9	58.1	9	119	9	310	14	4.3	14
26.7	22	55.0	22	118	18	303	18	4.3	9
26.7	10	54.9	18	116	22	303	9	4.2	22
26.4	13	54.0	7	115	14	298	22	3.9	19
25.7	7	53.4	10	113	10	298	12	3.9	12
25.4	18	53.1	6	111	12	298	19	3.7	18
25.4	8	53.0	13	110	3	295	7	3.7	3
25.1	4	52.8	8	109	7	293	6	3.4	7
24.6	12	52.4	12	109	13	292	3	3.3	6
24.6	1	50.7	14	108	19	283	8	3.3	2
24.6	6	50.5	4	107	6	278	5	3.1	8
24.1	5	50.5	3	106	4	278	10	3.1	5
23.9	3	49.5	15	103	2	276	13	3.1	1
23.6	16	48.7	5	103	15	274	2	3.0	13
23.1	14	47.9	1	103	8	265	21	3.0	10
22.9	20	47.6	2	102	1	262	20	2.9	4
22.6	15	47.0	20	102	5	262	4	2.8	15
21.8	17	46.3	16	99	16	261	11	2.8	21
21.3	11	45.1	17	98	17	257	1	2.8	16
20.6	2	44.3	19	96	11	255	16	2.7	20
19.8	19	43.1	11	94	20	253	17	2.7	17
18.3	21	40.4	21	92	21	253	15	2.7	11
mean 23.5		mean 49.9		mean 106		mean 280		mean 3.3	
LSD (5%) 1.2		LSD (5%) 7.6		LSD (5%) 16		LSD (5%) 6		LSD (5%) 1.1	

TABLE 7.— Correlation matrix : *Pinus halepensis*

	Variables	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}
x_1	Latitude	+1.0		-.51***			-.33*				+.33*									
x_2	Longitude		+1.0						-.31*											
x_3	Altitude			+1.0	+.49***	+.50***	+.51***	-.40**			+.54***									
x_4	Seed length				+1.0	+.95***	+.93***			+.70***	+.84***	+.52***								
x_5	Seed width					+1.0	+.93***			+.76***	+.84***	+.54***								
x_6	Seed weight						+1.0			+.77***	+.89***	+.56***								
x_7	Germination rate							+1.0												
x_8	Germination %								+1.0				+.38*							
x_9	Cotyledon number									+1.0	+.76***	+.66***								
x_{10}	Cotyledon length										+1.0	+.56***								
x_{11}	Hypotocyl length											+1.0	+.37*							+.31*
x_{12}	1-year height[1)]												+1.0							
x_{13}	2-year survival													+1.0	+.96***	+.79***	+.76***	+.73***	+.76***	+.57***
x_{14}	3-year survival														+1.0	+.77***	+.77***	+.76***	+.80***	+.64***
x_{15}	2-year height															+1.0	+.99***	+.87***	+.87***	+.62***
x_{16}	3-year height																+1.0	+.95***	+.92***	+.77***
x_{17}	5-year height																	+1.0	+.98***	+.90***
x_{18}	7-year height																		+1.0	+.89***
x_{19}	7-year diameter																			+1.0

1) Nursery height
* Significant at the 5% level
** Significant at the 1% level
*** Significant at the 0.1% level

TABLE 8.— Correlation matrix : *Pinus brutia*

	Variables	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
X_1	Latitude	+1.0	+.58**																	
X_2	Longitude		+1.0	+.60**			+.46*									+.68***	+.68***	+.60**		
X_3	Altitude			+1.0		+.46*	+.59**				+.48*									
X_4	Seed length				+1.0	+.88***	+.88***	-.49*	+.58**	+.61**	+.57**									
X_5	Seed width					+1.0	+.88***			+.65**										
X_6	Seed weight						+1.0	-.48*	+.50*	+.77***	+.43*									
X_7	Germination rate							+1.0	-.55*											
X_8	Germination %								+1.0		+.73***									
X_9	Cotyledon number									+1.0										
X_{10}	Cotyledon length										+1.0	+.49*		+.54*	+.52*					
X_{11}	Hypotocyl length											+1.0								
X_{12}	1-year height 1)												+1.0			+.80***	+.68***	+.53*		
X_{13}	2-year survival													+1.0	+.98***					
X_{14}	3-year survival														+1.0					
X_{15}	2-year height															+1.0	+.91***	+.68***		
X_{16}	3-year height																+1.0	+.83***	+.62***	+.55*
X_{17}	5-year height																	+1.0	+.82**	+.83***
X_{18}	7-year height																		+1.0	+.90***
X_{19}	7-year diameter																			+1.0

1) Nursery height
* Significant at the 5% level
** Significant at the 1% level
*** Significant at the 0.1% level

correlated with hypocotyl length, cotyledon length and cotyledon number. Germination rate was negatively correlated with altitude, both germination percentage and hypocotyl length were positively correlated with 1-year height. Hypocotyl length was positively correlated with 7-year diameter.

In *P. brutia*, the same trends as above were present for the seed characters; in addition seed weight and length were positively correlated with germination percentage and negatively with germination rate. In both species, the higher the germination percentage the faster the germination (i.e. the lower the score given for germination rate).

In *P. brutia*, longitude and nursery height (1-year-height) were correlated with 2, 3 and 5-year heights. In *P. halepensis*, 2-year height was correlated with all subsequent height measurements and with 7-year diameter.

In *P. halepensis* there was a significant positive correlation between height, diameter and survival throughout the measurements whereas the correlation was not statistically significant in *P. brutia*.

Principal Component Analyses. The results from the principal component analyses (computed on standardized components) are shown in *Tables 9 and 10*. The roots refer to the sum of squares of loadings for each axis. The largest loadings are underlined to emphasise the underlying factors.

Although the interpretation of components before and after rotation is the same, rotation was found to concentrate the factor loadings on some variables, making interpretation easier. The results from the rotated axes will therefore be used as a basis for discussion in this paper.

The four axes identified for *P. halepensis* account for 88% of the total biological variation; in *P. brutia* five axes account for a total of 86% of the same variation.

In *P. halepensis*, the main variables on axis 1 (accounting for 40% of the variation) are 2 to 7-year heights, 7-year diameter and 2 and 3-year survival; axis 2 (30.6%) shows large loadings for the morphological seed characters (seed length, width, weight) and for early seedling characteristics (cotyledon number and length), axis 3 (9.3%) combines large loadings in germination rate and percentage with

TABLE 9. — Principal component analysis : *Pinus halepensis*

Axis	1	2	3	4
Root	6.59	4.33	1.60	1.09
Fraction of total variance (%)	40.0	30.6	9.3	8.2
Probability	<0.001	<0.001	<0.001	<0.001
Input variables	Loadings			
Seed length	-0.00	0.20	-0.01	-0.12
Seed width	0.01	0.20	-0.04	-0.08
Seed weight	0.00	0.20	-0.05	-0.07
Germination rate	-0.01	-0.08	0.52	0.14
Germination %	-0.01	-0.07	-0.49	0.22
Cotyledon number	0.03	0.17	0.01	0.10
Cotyledon length	0.03	0.20	-0.05	-0.04
Hypocotyl length	0.04	0.08	0.35	0.44
1-year height 1)	0.03	-0.05	-0.06	0.70
2-year survival	-0.16	0.02	-0.12	-0.13
3-year survival	-0.16	0.01	-0.11	-0.13
2-year height	-0.16	-0.04	-0.04	0.06
3-year height	-0.16	-0.02	-0.01	0.03
5-year height	-0.17	-0.02	0.06	-0.03
7-year height	-0.17	-0.03	0.04	-0.00
7-year diameter	-0.13	0.00	0.12	0.01
Interpretation	Field performance	Seed size	Vigour	Early growth

1) Nursery height

N. B. **The horizontal lines in tables divide provenances into four classes which are the upper, middle and lower quartiles of the range. Provenance number refer to Tables 1 and 2 LSD = least significant difference at the 5% probability level.**

TABLE 10. — Principal component analysis : *Pinus brutia*

Axis	1	2	3	4	5
Root	5.26	3.79	2.30	1.36	1.07
Fraction of total variance (%)	21.1	18.9	16.8	14.7	14.6
Probability	<0.001	<0.001	<0.001	<0.001	<0.001
Input variables			Loadings		
Seed length	0.23	0.06	0.02	-0.03	-0.02
Seed width	0.28	0.02	-0.02	0.01	0.04
Seed weight	0.33	-0.02	-0.04	-0.06	0.12
Germination rate	0.02	0.17	0.09	-0.11	0.32
Germination %	-0.11	0.02	0.10	0.05	-0.39
Cotyledon number	0.36	-0.01	-0.03	0.02	0.23
Cotyledon length	-0.10	0.06	0.01	-0.12	-0.35
Hypocotyl length	-0.11	-0.01	-0.05	0.13	-0.40
1-year height 1)	-0.04	0.18	0.47	0.11	-0.04
2-year survival	-0.01	-0.01	0.05	0.46	-0.11
3-year survival	-0.04	0.01	0.08	0.48	-0.14
2-year height	-0.00	0.09	0.37	-0.02	0.02
3-year height	0.01	-0.05	0.28	0.02	0.08
5-year height	0.02	-0.25	0.05	-0.02	0.06
7-year height	-0.05	-0.37	-0.12	0.02	-0.01
7-year diameter	-0.03	-0.41	-0.19	0.03	-0.10
Interpretation	Seed size	Field performance	Field performance	Vigour	Early growth

1) Nursery height

large loadings in hypocotyl length. On axis 4 (8.2%) the largest loadings are for germination percentage, hypocotyl length and 1-year height.

In *P. brutia*, the main variables on axis 1 (21.1%) are the morphological seed characters (seed length, width and weight) and cotyledon number. Axis 2 (18.9%) shows large loadings for germination rate and for 1, 5 and 7-year heights and 7-year diameter; axis 3 (16.8%) combines germination percent and 1, 2, 3 and 7-year heights and 7-year diameter; axis 4 (14.7%), 2 and 3-year survival. On axis 5 (14.6%) the largest loadings are for germination rate and percentage, cotyledon number and length and hypocotyl length.

Canonical Analyses. The simple and partial correlation coefficients of input variables and canonical variates (i.e. the provenance mean and the canonical score respectively for each provenance and input variable) are shown in *Tables 11* and *12*. The statistically significant simple coefficients are emphasised by underlining. The partial coefficients are given in parenthesis.

In *P. halepensis,* the largest simple correlation coefficients in the seed origin data (B side) are in altitude on axis 1 and in latitude and altitude on axis 2. In the biological data (A side), the largest simple coefficients on axis 1 are found in seed length, width and weight and in cotyledon length; on axis 2 in seed weight and cotyledon length. Axis 1 accounts for 44.2%, axis 2 for 30.0% of the total variation.

A third axis identified for *P. halepensis* will not be considered because of its low significance (probability 0.22). The axis contained significant coefficients for longitude and germination percentage.

In *P. brutia,* the largest simple correlation coefficients in the seed origin data (B side) are in longitude on axis 1 and in altitude and longitude on axis 2. In the biological data (A side) the largest simple coefficients on axis 1 are found in 1, 2, 3 and 5-year heights; the main biological components on axis 2 are in seed size and weight, cotyledon length and 7-year height and diameter. Axis 1 accounts for 39.0%, axis 2 for 34.6% of the total variation.

A third non-significant axis identified for *P. brutia* (probability 0.72) contained significant coefficients for latitude, early seedling characteristics and survival.

TABLE 11. — Canonical analysis : *Pinus halepensis*

Axis	1		2	
Root	0.77		0.52	
Canonical correlation	0.88		0.72	
Fraction of total variance (%)	44.2		30.0	
Probability	<0.001		0.106	
Input variables	Simple correlation coefficients of input variables and canonical variates. Partial coefficients are shown in parenthesis			
A-side (A vs B)				
Seed length	-0.48**	(0.21)	0.26	(-0.10)
Seed width	-0.46**	(-0.42)	0.28	(-0.01)
Seed weight	-0.43**	(0.18)	0.35*	(0.24)
Germination rate	0.43**	(0.32)	-0.11	(0.04)
Germination %	0.08	(0.17)	0.12	(-0.07)
Cotyledon number	-0.22	(0.06)	0.17	(-0.22)
Cotyledon length	-0.48**	(-0.40)	0.36*	(0.18)
Hypocotyl length	-0.05	(0.25)	0.16	(-0.07)
1-year height 1)	-0.06	(-0.35)	0.23	(0.17)
2-year survival	0.06	(-0.12)	0.21	(0.13)
3-year survival	0.03	(0.20)	0.13	(0.00)
2-year height	0.17	(0.65)	0.01	(0.29)
3-year height	-0.01	(-0.27)	-0.10	(-0.18)
5-year height	-0.09	(-0.12)	-0.14	(-0.23)
7-year height	-0.07	(-0.42)	-0.07	(0.02)
7-year diameter	-0.22	(0.42)	-0.10	(0.29)
B-side (B vs A)				
Latitude	-0.04	(-0.73)	-0.72**	(-0.65)
Longitude	-0.11	(-0.65)	0.04	(0.01)
Altitude	-0.65**	(-0.87)	0.39*	(0.05)

1) Nursery height
* Significant at the 5% level
** Significant at the 1% level

TABLE 12. — Canonical analysis : *Pinus brutia*

Axis	1		2	
Root	0.97		0.85	
Canonical correlation	0.98		0.92	
Fraction of total variance (%)	39.0		34.6	
Probability	<0.001		0.138	
Input variables	Simple correlation coefficients of input variables and canonical variates. Partial coefficients are shown in parenthesis			
A-side (A vs B)				
Seed length	0.22	(0.68)	0.34*	(-0.72)
Seed width	0.06	(-0.67)	0.46*	(0.40)
Seed weight	0.28	(0.27)	0.53**	(0.31)
Germination rate	-0.18	(0.56)	-0.29	(-0.40)
Germination %	0.21	(-0.27)	0.29	(-0.47)
Cotyledon number	0.34	(0.00)	0.29	(0.11)
Cotyledon length	0.18	(-0.34)	0.47*	(0.56)
Hypocotyl length	0.15	(0.57)	0.21	(0.05)
1-year height 1)	0.52*	(-0.38)	-0.06	(-0.07)
2-year survival	-0.35	(-0.62)	-0.21	(0.30)
3-year survival	-0.30	(0.54)	-0.27	(-0.28)
2-year height	0.81**	(0.23)	0.16	(0.18)
3-year height	0.76**	(0.34)	0.10	(-0.05)
5-year height	0.58	(0.32)	0.24	(-0.39)
7-year height	0.23	(-0.76)	0.33*	(0.70)
7-year diameter	0.32	(0.54)	0.43**	(-0.33)
B-side (B vs A)				
Latitude	0.19	(-0.93)	0.01	(0.12)
Longitude	0.81**	(0.98)	0.35*	(-0.47)
Altitude	0.24	(-0.92)	0.89**	(0.91)

1) Nursery height
* Significant at the 5% level
** Significant at the 1% level

Discussion

At Jerilderie the variation in soil quality (especially in the *P. halepensis* trial) and susceptibility to flooding, can be clearly noticed in the results through significant variation between blocks in growth and survival. In the *P. brutia* trial the soil variation is less pronounced and the disadvantaged trees of *P. brutia* seem to have caught up by the time of the latest measurement (1974) when the differences between blocks in height, diameter and volume were no longer statistically significant. The performance of both species would have been improved had they been planted only on the lighter-textured, sandy soils: poor survival and growth in this trial was most pronounced on the heavier clay soils.

Rainfall figures at Jerilderie show big annual fluctuations throughout almost nine decades of recording. During the 7 years of provenance testing the extremes in annual rainfall were 189 and 835 mm. After four years of average rainfall following planting a drought was experienced in 1972, succeeded by two years with more than double the average rainfall. On the whole, the period 1968—1974 was wetter than average (mean annual rainfall for the 7 years 486 mm as opposed to the 88 year mean of 390 mm), partially explaining the surprising fact that *Pinus radiata* in the adjacent arboretum has survived well and shows a mean height of 520 cm and a mean diameter of 8.4 cm (13 trees) as opposed to the corresponding figures of 250 and 2.5 cm for *P. halepensis* and 280 and 3.3 cm for *P. brutia*.

In both *P. halepensis* and *P. brutia* altitude is the geographic variable most closely correlated with various seed and seedling characteristics. Seed size and weight seem to give the best indications of germination potential and early seedling development. Although there are distinct provenance differences in seed and seedling characteristics no statistically significant correlation can be found in either species between these and later survival and growth of the trees.

Germination vigour (as expressed through germination rate and percentage) has in several species been found to correlate with hypocotyl length and subsequent height growth, suggesting that this parameter could be used in early tests to predict later development (Venator 1973 and 1974, Morgenstern 1974). This correlation is not significant in *P. halepensis* or in *P. brutia*, although in *P. halepensis* hypocotyl length correlates with 7-year diameter. The correlation suggests that a connection may exist between hypocotyl length and later growth in *P. halepensis*.

Although 1-year height in *P. brutia* correlates with the three subsequent height measurements correlation with the latest measurement (7-year height) is not statistically significant. The earliest growth figures that consistently correlate with subsequent height growth are 2-year height in *P. halepensis* and 3-year height in *P. brutia*.

Conclusions based on the principal component analysis and the canonical analysis on cause-and effect relationships will be more reliable than those based on the correlation analysis, which is strictly an analysis of association between pairs of characters.

In the principal component analyses, the causes underlying the identified axes can be interpreted as (1) field performance (2) seed size (including seed weight) (3) vigour (as expressed by the physiological factors of germination and survival) and (4) early growth (*Tables 9* and *10*). Corresponding groupings were found through the simple correlation coefficients in the canonical analysis (*Tables 11* and *12*). In *P. halepensis* large simple coefficients in altitude (axis 1) and in latitude and altitude (axis 2) combine with large coefficients in seed size and weight. In *P. brutia*, longitude combines with field performance (axis 1), altitude and longitude with seed size (axis 2).

The partial correlation coefficients in some cases aid the interpretation of data. A large simple coefficient could be largely due to the effects of related variables. However, a large partial coefficient as well as a large simple coefficient indicates that the simple coefficient reflects a real correlation between the input variable and the canonical variate. A large partial coefficient without a corresponding large simple coefficient indicates that the correlation found is small in comparison with that of other input variables. In *P. halepensis*, seed width thus appears to be the component of seed size primarily responsible for the correlation between seed size and altitude (*Table 11*).

The connection between seed size and weight and early seedling development is well documented in the literature, and several authors have in particular stressed the relationship between seed size and weight, number of cotyledons and cotyledon and hypocotyl lengths (Yeatman 1966, Morgenstern 1969). Seed size, combining in the principal component analysis with the factor of cotyledon number and length, accounts in *P. halepensis* for 31% of the total biological variation and in *P. brutia*, for 21%.

In the canonical analysis, seed size and weight are connected with altitude and latitude in *P. halepensis*. Large-seeded genotypes are as a rule favoured in adverse conditions, i.e. in low rainfall areas and in areas where the growing season is relatively short and temperatures low (Toumey 1916, Wells 1964). Harsher conditions generally prevail at higher altitudes (short growing season, low temperatures) and this results in a positive canonical correlation between seed size and altitude (axis 1). The inverse canonical correlation between latitude and seed weight (axis 2) can be explained by the fact that low latitude provenances of the species originate in the southern part of the Mediterranean where arid conditions prevail. As the natural distribution of *P. brutia* mainly extends in an east-west direction there are no drastic changes in climate comparable to the latitudinal changes in *P. halepensis*; accordingly, seed size in *P. brutia* is connected mainly with altitude.

In *P. halepensis* there is a close relationship between growth and survival (see correlation and principal component analyses). However, no distinct relationship can be traced between geographic origin and growth at Jerilderie in this species (see correlation and canonical analyses), indicating that field performance is largely independent of seed origin. In *P. brutia*, large simple correlation coefficients in longitude combine with large coefficients in growth on axis 1 of the canonical analysis. This association, which also is apparent in the correlation analysis, reflects the taxonomic change from the true *P. brutia* at low longitudes to *P. eldarica* further east.

It is interesting to note that in *P. brutia*, axis 2 in the canonical analysis contains large simple coefficients for 7-year height and diameter as well as for seed size, whereas height up to age 5 is found on axis 1. A corresponding phenomenon can be found in the principal component analysis, where the provenances of *P. brutia* are split into two groups (axes 2 and 3). On axis 3, height at age 7 correlates inversely with previous height figures in contrast to a direct correlation on axis 2. These trends are strengthened when increments instead of heights are used in the computations.

At age 5 the field trial experienced a drought, which evidently affected the growth pattern of the trees. The provenances of *P. brutia* which improved their ranking at age 7 after having earlier shown a constant or downward trend originate in a well defined geographic area. They are provenances 5 and 20 (Rhodes), 8 (Cyprus), and 21 (Thasos). Provenances 2 (*P. pithyusa* var. *stankewiczii*, USSR), 10 (Lebanon), and 3 and 15 (Turkey) show a distinct downward trend in ranking after the drought year.

As shown above, seed size tends to increase with the incidence of adverse environmental conditions in areas of natural occurrence. This explains the positive relationship between seed size and the drought resistant provenances of *P. brutia* (axis 2 in the canonical analysis).

At the time of planting *P. halepensis* had a definite advantage over *P. brutia* (mean 1-year heights 19.8 and 15.2 cm) but four years later in 1972 *P. brutia* had caught up with and surpassed *P. halepensis*. *P. brutia* thus seems to be better adapted than *P. halepensis* to the growth conditions prevailing at Jerilderie.

Provenances 9 and 22 of the *P. brutia* complex, *P. eldarica*, are clearly superior not only in form but also in growth. Both provenances are Iranian land races. Provenance 9 was collected in the mountainous Khaf district in eastern Iran; seed of provenance 22 was obtained from the Forestry Faculty Park in Karadj.

The two provenances of *P. pithyusa* (provenances 1 and 2) are average in growth at Jerilderie, but they have during the last few years shown a downward trend in ranking.

Provenances 12, 18 and 19 of *P. brutia*, noted in 1974 for their attractive form, are among the best-growing trees at Jerilderie. Provenance 17 is poor in growth. The best provenance in 1974, provenance 14, which shows a constant upward trend in ranking, is of average form. All of these provenances originate in Turkey. Provenance 12 is an inland provenance from the Bucak district, Burdur; provenance 19 originates in the Yilemli district, Mugla; and provenance 14 is from Lengume Loc, north of Kas (all three locations are in the southern parts of the country). Provenance 18 originates in the Alacan district, Bafra (northern Turkey); provenance 17 in the Sucati district, Maras (the interior of the southern-eastern Mediterranean area).

According to Arbez (1974) the best stands of *P. brutia* in Turkey are found at medium altitudes (500—900 metres) in the Mediterranean area. He mentions stands near Mugla and Bucak as being of excellent form, characterised by straight stem, fine, rather short branches and wide branch angles. The Maras provenance, growing in a dry, continental climate and on shallow soil, is described as short and stocky but with relatively good stem form and fine branches. Special mention is also given by Arbez to the isolated populations in the eastern Black Sea region in the vicinity of Bafra. The above descriptions coincide remarkably well with the behaviour of the provenances growing at Jerilderie. Arbez further notes that low-altitude coastal provenances in the Mediterranean area generally are of poor growth and form. Provenance 15, originating on the south-western coast of Turkey at an elevation of some 50 m a.s.l. performs poorly at Jerilderie. Provenance 16 (Fethiye, Bayir Loc), average in form and poor in growth at Jerilderie comes from an area in which the stands are of excellent form but of fairly poor growth. Provenance 3, which is average in height and diameter growth at Jerilderie, originates in an inland stand in south-western Turkey (Saridere, Pomucak). According to Arbez trees in the marginal populations in inland areas are often inferior in height growth but have a diameter growth comparable to trees in populations growing in better ecological conditions.

The Cyprus provenances of *P. brutia*, 6, 7 and 8, satisfactory in both growth and form at Jerilderie, were collected from better-than-average stands of good stem form and branching habit.

P. halepensis is generally considered to be an inferoir species to *P. brutia* in growth and form (Debazak and Tomassone 1965, Allegri 1973).

Provenance 41, the outstanding provenance in the *P. halepensis* group, originates in the Adana district in southeastern Turkey in an area where *P. halepensis* and *P. brutia* overlap (Selik 1958). The two species hybridise in nature (Mirov *et al.* 1966), it is therefore tempting to speculate on whether introgression may have played some part in population development in this area.

Of the three Italian provenances of *P. halepensis* noted for their good form, the southernmost provenance, provenance 4, excels in both height and diameter growth. The northernmost of the provenances, provenance 2, is poor in growth. Of the well-formed Tunisian inland provenances 10, 20, 28 and 30, only provenances 20 and 28 are satisfactory in growth. The Moroccan provenance, provenance 34, originating in an area with a dry period of four months, is average in growth. Provenance 42 from Greece, noted for its bad stem form, ranks high in growth. The Algerian semi-arid provenance (provenance 40) is among the best quartile in height and diameter growth at Jerilderie.

The Tunisian provenances 14, 17, 18 and 27 are among the most vigorous provenances in the *P. halepensis* group at Jerilderie. They originate in the same inland areas of Tunisia as the ones noted for good form but of only average growth.

Conclusions

The most distinct feature in both *P. halepensis* and *P. brutia*, apparent in all analyses made, is the clear split between seed and seedling characteristics on the one hand and field performance on the other. Another noteworthy feature is the lack of distinct variation patterns in relation to latitude and longitude; this may be due to the fact that the natural forests around the Mediterranean have generally been disrupted by man and subject for centuries to dysgenic selection. The altitudinal variation found in *P. brutia* can probably be explained to a large extent by the same factors: high-altitude stands are less accessible and are therefore often of better quality than the remnants of forest at low altitudes. As the natural range of the two species is discontinuous and population size generally is fairly small genetic drift may also have contributed to the non-systematic variation patterns (Wright and Bull 1962).

When selecting provenances of *P. halepensis* and *P. brutia*, strong emphasis should be placed on the phenotypic appearance of the stands from which seed is collected. Long-term trials in the field seem to be essential to fully evaluate the various provenances, as neither seed nor early seedling characteristics have given any clear indications of later growth and development of the progeny, in which the impact of irregularly occurring drought years will be of major significance.

Populations within the *P. brutia* group, notably *P. eldarica*, are promising in the Jerilderie area and of some tens of species tried there, they come second only to *P. radiata* in growth rate. The stem form of the medium- to high-altitude Turkish populations of *P. brutia* is attractive and in addition these provenances seem to grow satisfactorily in the semi-arid conditions at Jerilderie. Provenances from the Greek islands appear to be comparatively drought resistant, and if they prove to be superior in this respect in the future, provenance hybridization could possibly be used to improve their stem form and branching habit.

The trials at Jerilderie will be continued to determine whether more pronounced differences in ranking will occur: greater differentiation between provenances is probable if a severe drought is experienced.

Production forestry on a large scale is unlikely in the areas concerned, but *P. brutia* (including *P. eldarica)* can certainly be considered to be a promising alternative conifer to the fairly drought-susceptible radiata pine in erosion control and in shelterbelt, amenity and windbreak plantings.

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Summary

Forty-two provenances of *P. halepensis,* 18 provenances of *P. brutia,* 2 provenances of *P. eldarica* and 2 provenances of *P. pithyusa* were tested. Morphological and physiological characteristics were recorded both in the nursery at Canberra and in the field in semi-arid conditions at Jerilderie (south-eastern Australia). Differences in height, computed on plot and provenance means, varied from significant at the 5% level to highly significant at the 0.1% level between provenances during the first three years in the field but were non-significant for *P. brutia* at age 5 and 7. However, there were significant differences between provenances in diameter at age 7 in both *P. halepensis* and *P. brutia*. *P. brutia* grew faster and was generally of better stem form than *P. halepensis*.

Correlation and principal component analyses computed on provenance means indicated that neither seed nor early seedling characteristics give any clear indication of later growth and development of the progeny. The correlation and canonical analyses suggest that some morphological and physiological differentiation has occurred in relation to altitude (elevation of seed source). However, perhaps because of the intervention of man over centuries and because of possible genetic drift in the small, fairly isolated populations little differentiation is apparent in relation to latitude and longitude except for the taxonomically-recognised differentiation within the *P. brutia* complex.

The phenotype of trees in the original stands of *P. brutia* closely resemble the progeny growing at Jerilderie. The indications are that genotype × environment interactions are low and that form of the trees is under fairly rigid genetic control. Extreme care is therefore warranted when selecting stands for seed collection.

Provenances within the *P. brutia* group, notably the medium- to high-altitude Turkish and Greek provenances of *P. brutia* and the Iranian land races of *P. eldarica,* show some promise as alternative species to *P. radiata* in shelterbelt, amenity and windbreak plantings in the semi-arid areas of south-eastern Australia.

Key words: Provenance trials, Geographic variation, Early growth, Multivariate analysis, *Pinus halepensis* Mill., *P. brutia* Ten., *P. eldarica* Medw., *P. pithyusa* Stev.

Zusammenfassung

Die vorliegende Untersuchung erfaßte 42 Herkünfte von *P. halepensis* Mill., 12 Herkünfte von *P. brutia* Ten. sowie je 2 Herkünfte von *P. eldarica* Medw. and *P. pithyusa* Stev. Morphologische und physiologische Charakteristiken wurden sowohl im Pflanzgarten von Canberra, wie auch in einem Feldversuch unter semi-ariden Bedingungen in Jerilderie (Südost-Australien) studiert. Während der ersten drei Jahre waren die Höhenunterschiede zwischen den Provenienzen (berechnet auf der Basis von Block- und Provienzmittelwerten) signifikant ($P = 0.05$) bis hochsignifikant ($P = 0.001$). Die Höhenunterschiede der fünf- und siebenjährigen *P. brutia* erwiesen sich als nicht gesichert. Hingegen waren die Durchmesserunterschiede zwischen den Provenienzen der siebenjährigen *P. halepensis* und *P. brutia* gesichert. Im allgemeinen war *P. brutia* von besserer Wuchsleistung und besserer Stammform als *P. halepensis*.

Die Mittelwerte der verschiedenen Provenienzen wurden mit einer Korrelations- und einer Hauptkomponentenanalyse untersucht; die Resultate gaben aber keinerlei Hinweise auf klare Zusammenhänge zwischen Charakteristiken des Saatgutes oder der Sämlinge einerseits und des Wachstums oder der Entwicklung der Nachkommenschaft andererseits.

Die Ergebnisse einer weiteren Korrelations- und einer kanonischen Korrelationsanalyse deuten jedoch an, daß unter dem Einfluß der Meereshöhe einige unterschiedliche morphologische und physiologische Differenzierungen stattgefunden haben. Außer im taxonomisch gut erfaßten *P. brutia*-Komplex waren kaum Unterschiede zwischen Herkünften verschiedener Längen- und Breitengrade feststellbar, was auf den Jahrhunderte alten menschlichen Einfluß oder auf genetische Verschiebung in kleinen, relativ isolierten Populationen zurückgeführt werden könnte.

Die Phänotypen der Bäume in den Mutterbeständen von *P. brutia* sind denjenigen der Nachkommen von Jerilderie sehr ähnlich. Anscheinend haben Wechselwirkungen zwischen Genotyp und Umwelt wenig Einfluß auf die Baumform, die weitgehend genetisch fixiert zu sein scheint. Äußerste Vorsicht ist deshalb bei der Auswahl von Saatgutbeständen geboten.

In den semi-ariden Gebieten Südost-Australiens bieten sich Provenienzen der *P. brutia* Gruppe, insbesondere griechische und türkische Herkünfte von mittleren bis höheren Lagen, sowie persische Landrassen von *P. eldarica* als vielversprechende Alternativen zu *P. radiata* an, wo diese Baumart als Windschutzstreifen und als Schutz- und Schattengehölz etwa in Erholungsräumen oder auf Viehweiden angebaut wird.

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Early Growth of Progenies from some phenotypically superior White Spruce Provenances in Central Newfoundland

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Introduction

The widespread distribution of white spruce (*Picea glauca* (MOENCH) VOSS) in Canada and northern U.S.A., combined with its high economic value, has prompted research on its genetic improvement in several parts of the continent. Detection of superior provenances, and verification of their genetic superiority, is an important aspect of this research. One such study was started in the fall of 1971 in Newfoundland to verify the genetic superiority of a number of phenotypically superior trees of white spruce located in small, partially isolated stands in the Exploits River Valley in central Newfoundland. Some results which indicate that the characters of cone morphology are genetically controlled but not associated with height growth, and that the heritability of these characters differs at the two locations under study, have already been reported (KHALIL, 1974). This paper presents further results concerning germination, survival and early height growth of progenies from these trees.

Material and Methods

Phenotypically superior trees of white spruce have been located at several sites in the Exploits River Valley in central Newfoundland (Forest Section B.28a; ROWE 1972) in natural second growth stands as individual trees or small groups of trees. Such trees have distinctly superior height and diameter growth. The study was restricted to two locations in the above tract, near Frenchman's Pond (latitude 48° — 50' N., longitude 55° — 40' W.) and Lake Douglas (latitude 48° — 30' N., longitude 56° — 40' W.). The two locations, which are about 50 miles apart, have similar climate and both are situated on gently undulating, well-drained sites. At each location five average ("ordinary") and five exceptionally tall ("plus") trees were selected. *Table 1* shows the phenotypic differences between these classes of trees.

Table 1. — Mean age, height and breast height diameter of "plus" and "ordinary trees."

	Frenchman's Pond			Lake Douglas		
	Age (yrs)	Height (m)	Diameter (cm)	Age (yrs)	Height (m)	Diameter (cm)
"Ordinary" trees	23	9.82	15.5	56	9.39	21.3
"Plus" trees	26	13.17	25.9	51	13.53	30.2

Seeds were collected from the 20 trees in 1971. Samples of current year's foliage from each selected tree and of soil from beneath the same trees were collected in September 1972 and chemically analysed to test for the existence of differences which might be responsible for variations in growth. The soil samples were analysed for texture, total organic matter content, organic carbon, C/N ratio, pH, cation exchange capacity, and total and available nitrogen, phosphorus, potassium, calcium and magnesium. The means of the above variables for "plus" and "ordinary" trees at both locations were compared using Student's t-test. The needles were analysed for nitrogen, phosphorus, potassium, calcium, and magnesium contents, and the means were compared in the same way.

Genetic studies comprised a four- replicated experiment in a laboratory germination test (25 seeds per plot) in February, 1972 and a five-replicated nursery experiment at Pasadena, Newfoundland (400 seeds per plot). Randomized complete block design was used in both cases and progenies were kept separate by individual parent.

Data were collected on the germination percent in the laboratory experiment as also on the germination and survival percent and height of 10 randomly selected seedlings in each plot at the age of 2 years.

The data were tested by analysis of variance followed by Student-Newman-Keul's multiple range test and single degree of freedom comparisons between the progenies of the above classes of trees. Narrow sense individual tree heritability of 2-year height growth was calculated from the analysis of variance, using Wright's formulae 61 and 62 (WRIGHT 1962).

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