PROVENANCE VARIATION IN *PINUS RADIATA* AT TWO SITES IN NORTHERN GREECE

C. VARELIDES

Forest Research Institute,
Terma Alkmanos, Athens 115.28, Greece

(Received for publication 29 May 1995; revision 8 January 1996)

ABSTRACT

Fifteen provenance lots of *Pinus radiata* D. Don, from three Californian populations (Año Nuevo, Monterey, Cambria) and two Australian sources, were tested on two nearby sites of contrasting quality (ultrabasic and schist) in northern Greece.Tree height, diameter at breast height, survival, and stem form were assessed at the seventh year.

No differences were found ($p > 0.05$) between the provenances in any of the traits in the across-sites analysis, nor were any provenance × site interactions statistically evident. In within-sites analyses, differences were identified ($p = 0.03$) between the provenances on the ultrabasic site for survival but not for any other trait. No across-sites differences were found between the populations for any trait.

Tree height and stem form were markedly better on the loamy ultrabasic site than on the sandy schist.

Keywords: provenance trials; site; *Pinus radiata.*

INTRODUCTION

Pinus radiata of restricted natural occurrence along the Californian coast of the United States has been used extensively as an exotic species in many parts of the world. It is considered capable of rapid growth and high volume production on suitable sites in a Mediterranean climate (Eccher 1970). The first recorded introduction in Greece was in 1913 as a specimen in the Arboretum of Vytina (central Peloponnese). Around the Mediterranean *P. radiata* rates as a demanding species, if its potential is to be realised, as it is vulnerable to drought, poor soil aeration, calcareous soils, and frost. Owing to the variability of the forest sites in Greece, the use of the species is limited to selected spots within other conifer plantations; therefore, provenance variation could be very important for expanding its use, if more suitable provenances could be identified for the local conditions.

Pinus radiata seed, including 13 seedlots of an international collection made in California (Eldridge 1978) and two sources from Australia, was obtained from CSIRO Australia by the Project FAO:UNDP/GRE/78/003. It was used for establishing a provenance trial on two sites in the Project pilot plantation at Nigrita in northern Greece, adjacent on both sites to a *P. muricata* D. Don provenance trial (nine origins of the same CSIRO collection). Early observations (Cooling & Varelides 1986) have shown superior height growth (in terms of the two species' overall means) of *P. radiata* compared with *P. muricata*. Faster growth of *P. radiata* than *P. muricata* was also reported in trials in Turkey (Simsèk & Tulukçu 1983), Chile (Barros & Rojas 1986), and South Africa (Falkenhagen 1991a).

MATERIALS AND METHODS

Sites

The Nigrita plantation in the Serres district in northern Greece (long. 23°30′–34′, lat. 40°49′–52′, alt. 420–660 m) was established with *P. pinaster* Aiton on hilly land in an extensive oak coppice area with scattered openings of grazed pasture of variable size. It is a winter rainfall area with mean annual precipitation of 600 mm and mean monthly temperature ranging from 5°C (January) to 25°C (August). Soils range from relatively heavy to friable, depending on the parent material which is mainly schist but with a considerable area of ultrabasic igneous rocks.

Two *P. radiata* trials were established, one on ultrabasic igneous rocks (mainly peridotites and biotite gneiss) and the other on mica schist, representing the two major soil types of the plantation. The ultrabasic site is in mid-slope at 500 m altitude, south to south-east aspect, with 20% slope and deep (60–120 cm) chromic luvisols (FAO-UNESCO classification) soil. The schist site is in the upper slope near the top of a ridge, at 470 m altitude, south to south-west aspect, at 10% slope and shallow to medium deep (30–60 cm) orthic acrisol soil (Nakos 1982).

Provenances

Pinus radiata seed (Table 1) included 13 native provenances (seedlots or subpopulations) from three Californian mainland populations (Año Nuevo, Moneterey, and Cambria) of the Californian CSIRO collection (1978), plus two sources from Australia (Canberra ex Guadalupe and Tallaganda Seed Orchard). In total, 15 provenances were tested on both sites. The plants were raised in the nursery for one growing season, in polyethylene bags, and planted out by November of the same year.

Experimental Layout

The two trials were of randomised block design with three replicates per site. Owing to a shortage of plants in three of the 15 provenances, only two block replicates were complete with all 15 provenances on both sites. Thus, provenance S12589 was missing from the third block on both sites, provenance S12593 was missing from the third block on the ultrabasic site, and provenance S12594 was missing from the third block on the schist site. The experimental plot consisted of 15 trees in three rows of five trees. Spacing was 3 × 2 m. There were no internal border rows, but a double row of the same species surrounded all external plot edges. In total, 1290 experimental trees were planted.

Assessments and Data Analysis

Measurements of survival (Sr) and tree height (Ht) began in the second year (October-November, i.e., at the end of the second season after planting), while measurements of

TABLE 1–*Pinus radiata* provenances and populations tested.

Australian stock numbers	Geographical location		Latitude (°)	Longitude (°)	Altitude (m)	Number of trees collected
S 12585	Año Nuevo	Inland Central	37.10	122.25	200	40
S 12586	Año Nuevo	Coastal strip	37.10	122.28	20	70
S 12587	Año Nuevo	Inland Swanton	37.07	122.23	150	40
S 12588	Año Nuevo	Inland Northern	37.13	122.30	140	29
S 12589	Monterey	Monterey-Del Monte	36.58	121.87	45	37
S 12590	Monterey	Coastal sand dunes	36.62	121.95	30	55
S 12591	Monterey	Jacks Peak Park	36.55	121.87	200	61
S 12592	Monterey	Huckleberry Hill	36.58	121.92	135	35
S 12593	Monterey	Point Lobos-Yankee	36.50	121.95	50	22
S 12594	Monterey	Carmel Highlands	36.50	121.92	330	34
S 12595	Cambria	Scott Rock Inland	36.58	121.07	192	24
S 12596	Cambria	Pico Creek	35.62	121.15	75	26
S 12597	Cambria	Cambria Town	35.57	121.10	75	49
S 12657	Australia	Canberra ex Guadalupe*				
S 12176	Australia	Tallaganda Seed Orchard				

* From pure Guadalupe Island seed parents which had been pollinated almost 100% by local Australian *P. radiata* of mainland origin

diameter at breast height (Dm) began in the sixth year. Foliar damage (possibly by frost, although boron deficiency could not be excluded completely) was observed, followed usually by insect attack to the leading shoot which was replaced by a lateral one. The stem form (St) was expressed as percentage of the undeformed stems (never damaged) among the total surviving stems per plot. The basic data units used for statistical analysis were from the seventh year after planting, and comprised plot means for tree height (m) and diameter (cm), and arcsin-transformed values for survival (%) and stem form (%) as defined above.

Prior to statistical analysis the missing values, as described in the experimental layout, were calculated with subsequent approximations (Snedecor & Cochran 1967). For each trait, analysis of variance was carried out over the two sites (Table 2) and for each site (Table 3).

Alternative tests existed for some effects, depending on what other effects were significant. Testing populations against seedlots within populations was based on the conservative assumption that the latter represented a random rather than a fixed effect. Likewise, testing

TABLE 2–Form of across-sites analysis of variance

	Source	Degrees of freedom	F-test denominator
1	Sites	1	2
2	Blocks (Sites)	4	7
3	Provenances overall	14	7
4	Populations	4	5
5	Seedlots (populations)	10	7
6	Provenances × sites	14	7
7	Residual	52	
8	Total	85	

TABLE 3–Form of within-site analysis of variance

	Source	Degrees of freedom	F-test denominator
1	Blocks	2	5
2	Provenances overall	14	5
3	Populations	4	4
4	Seedlots (populations)	10	5
5	Residual	26	
6	Total	42	

provenances against the provenance × site interaction rather than against the residual (Table 2) was based on the very conservative assumption that the sites also represented a random effect.

RESULTS

Population means are shown for the respective sites in Table 4 and individual provenance means across the two sites are shown in Table 5.

TABLE 4–Population (in parentheses the number of provenances per population tested) means for form traits for each site; height (Ht), diameter (Dm), survival (Sr), and stem form (St).

Populations	Ultrabasic site				Schist site			
	Ht (m)	Dm (cm)	Sr (%)	St (%)	Ht (m)	Dm (cm)	Sr (%)	St (%)
Año Nuevo (4)	4.40	6.96	99.4	81.5	3.52	7.74	99.4	49.8
Monterey (6)	4.66	7.27	98.6	83.2	3.39	7.07	97.3	58.5
Cambria (3)	4.48	7.19	94.6	82.8	3.51	7.49	97.6	60.4
Canberra (1)	5.07	7.82	92.4	78.1	3.37	7.87	99.2	59.7
Tallaganda (1)	4.72	7.20	100.0	81.3	3.42	7.26	95.6	40.6

TABLE 5–Individual provenance means over the two sites for the four traits assessed; height (Ht), diameter (Dm), survival (Sr), and stem form (St).

Provenance		Ht (m)	Dm (cm)	Sr (%)	St (%)
Año Nuevo	12585	3.94	7.42	97.8	66.3
Año Nuevo	12586	4.09	7.48	99.6	70.4
Año Nuevo	12587	3.97	7.29	99.8	67.3
Año Nuevo	12588	3.85	7.22	99.8	62.4
Monterey	12589	3.81	6.93	98.3	70.1
Monterey	12590	3.85	7.14	94.9	63.4
Monterey	12591	3.96	6.68	96.4	72.4
Monterey	12592	4.16	7.25	99.8	65.7
Monterey	12593	4.19	7.41	99.3	83.0
Monterey	12594	4.19	7.62	97.0	68.9
Cambria	12595	4.04	7.17	96.0	74.8
Cambria	12596	3.86	7.30	91.4	68.9
Cambria	12597	4.38	7.84	96.7	69.3
Tallaganda	12176	4.07	7.23	98.7	62.1

The across-sites analysis of variance (Table 2) showed no significant differences among provenances overall ($F \leq 1.05$), nor among populations. Provenance × site interactions were similarly non-significant, much the strongest indication of such interactions being for survival ($F_{14, 52 \, df} = 1.67$, $p \approx 0.1$).

The within-site analysis of variance (Table 3) showed statistically significant differences among provenances for survival at the ultrabasic site ($F_{14, 26} = 2.27$, $p \approx 0.03$). The worst there were 12590 (87%) and 12596 (89%) and the best were 12588, 12591, 12592, and 12176 (all 100%). Provenance differences overall were not evident for any other trait within either site ($F < 1$). There was no indication of statistically significant population differences other than for stem form at the schist site ($p \approx 0.1$). Adopting the alternative assumptions concerning fixed or ramdom effects had no material effect on the picture of provenance or population differences.

Site differences (Table 4) were strong and statistically significant for height and stem form, the ultrabasic site being the better, but not for diameter or survival ($F < 1$).

DISCUSSION

The one example among the various tests of statistically significant provenance variation, that for survival at the ultrabasic site, could well be a fortuitous Type 1 error, particularly as the data properties for the trait were not ideal.

The general absence of statistical differences between *P. radiata* provenances or populations may have been associated with limited replication. However, the adjacent *P. muricata* trial, with the same number of replications (three) as and fewer degrees of freedom than the *P. radiata* trial, has clearly shown the growth differences between the provenances (Varelides 1995; Cooling & Varelides 1986).

Absence of growth differences between *P. radiata* provenances, and the importance of the site, were reported in a trial in Greece (Matziris 1979a), where four provenances (two from Australia, one from New Zealand, one from Spain) were tried on three sites; in wood density the provenances again did not show any differences while the sites did (Matziris 1979b). In an earlier assessment (Varelides 1977) of that trial, where the height and survival on five sites (including two more sites in northern Greece not analysed by Matziris) was used, site differences were evident for height but there were no significant differences between the provenances.

In Turkey, 6-year-old trials of *P. radiata* provenances planted on five sites showed no differences in growth between the provenances, but significant differences between the sites (Simsèk & Tulukçu 1983). In France, in a 2-year-old trial, there was no difference in growth rate between the Californian mainland populations of *P. radiata*, but differences in frost resistance were detected (Alazard & Destremau 1981).

Although no differences between the *P. radiata* provenances in terms of growth were reported in the Mediterranean region, such differences were found in trials of the same material elsewhere. Thus, in a South African trial (Falkenhagen 1991b) with 16 provenances (13 of which were obtained from the same CSIRO collection) on six sites, differences were reported in growth rates between the populations on some of the sites at the eighth year. In the across-sites analysis, no differences were found among the seedlots within the mainland native populations, while there were distinct site differences in volume growth. Genetic variation in growth and other characters between the populations have been reported frequently elsewhere (Burdon & Bannister 1973; Shelbourne *et al.* 1979; Nicholls & Eldridge 1980; Old *et al.* 1986), although differences in growth rate among seedlots of Californian mainland origin were usually minor.

Site differences in volume growth in the South Africa trials cited above (Falkenhagen 1991b) were related to "the highest annual precipitation for constant effective soil depth". The considerable literature on soil characteristics in relation to productivity of *P. radiata* (for example, Schlatter *et al.* (1986) in Chile and Turvey *et al.* (1986) in Australia) underlines the importance of soil depth and texture (influencing the water-holding capacity), while chemical soil parameters have a lesser and varying influence. The present results accord with the cited reports since the better site on ultrabasic rock had deeper and less sandy soil, better water-holding capacity, and less exchangeable calcium than the schist.

The present results and the literature cited indicate that no differentiation in early growth emerges between *P. radiata* provenances or populations of Californian mainland origin under the Greek conditions. The expansion of *P. radiata* planting, therefore, where it outgrows the local pines should be based on the careful selection of suitable sites but the origin of the seed seems of minor importance. However, taking into account the reported results elsewhere, further investigation from more sources on better sites might be of interest in the future.

REFERENCES

ALAZARD, P.; DESTREMAU, D.X. 1981: De l'expérimentation en France de *Pinus radiata*. *Annales de récherches sylvicoles 1981, AFOCEL*: 5–33.

BARROS, A.S.; ROJAS, V.P. 1986: Site productivity and relation to various species and provenances. Pp.168–87 *in* Proceedings of "Workshop for Evaluating the Productivity of Forest Sites", 22–24 April 1982, Valdivia, Chile. Facultad de Ciencias Forestales, Universidad Austral de Chile.

BURDON, R.D.; BANNISTER, M.H. 1973: Provenances of *Pinus radiata*: their early performance and silvicultural potential. *New Zealand Journal of Forestry 18(2)*: 217–32.

COOLING, E.N.G.; VARELIDES, C. 1986: "Final Report: Plantation Silviculture". FAO:UNDP/GRE/78/003, W.D. 42, Athens, Greece.

ECCHER, A. 1970: Sulle possibilita d'impiego del *Pinus radiata* nell'Italia meridionale. *Cellulosa e Carta, N7*: 27–38.

ELDRIDGE, K.G. 1978: Seed collections in California in 1978. *CSIRO Division of Forest Research Annual Report 1977-78*: 8-17.

FALKENHAGEN, E.R. 1991a: Provenance variation in *Pinus muricata* in South Africa. *Silvae Genetica 40(2)*: 50–7.

———1991b: Provenance variation in *Pinus radiata* at six sites in South Africa. *Silvae Genetica 40(2)*: 41–50.

MATZIRIS, D. 1979a: Adaptability of *Pinus radiata* in Greece. Seed source study results of one decade. *Ministry of Agriculture, Athens, Greece, Forest Research Institute Report No.103.*

———1979b: Variation in wood density in radiata pine grown from four seed sources at two sites in Greece. *Silvae Genetica 28(2–3)*: 104–6.

NAKOS, G. 1982: "Site and Soil Survey: Nigrita Pilot Plantation Area". FAO:UNDP/GRE/78/003, W.D. 9, Athens Greece.

NICHOLLS, J.W.P:; ELDRIDGE, K.G. 1980: Variation in some wood and bark characteristics in provenances of *Pinus radiata* D.Don. *Australian Forest Research 10*: 321–35.

OLD, K.M.; LIBBY, W.J.; RUSSELL, J.H.; ELDRIDGE, K.G. 1986: Genetic variability in susceptibility of *Pinus radiata* to western gall rust. *Silvae Genetica 35(4)*: 145–9.

SCHALTTER, J.; GERDING, V.; BONNEFOY, M. 1986: Site factors of major importance for the productivity in *Pinus radiata*. Pp.61–97 *in* Proceedings of "Workshop for Evaluating the Productivity of Forest Sites", 22–24 April 1982, Valdivia, Chile, Facultad de Ciencias Forestales, Universidad Austral de Chile.

SHELBOURNE, C.J.A.; BURDON, R.D.; BANNISTER, M.H.; THULIN, I.J. 1979: Choosing the best provenances of radiata pine for different sites in New Zealand. *New Zealand Journal of Forestry 24(2)*: 288–300.

SIMSÈK, Y.; TULUKÇU, M. 1983: Growth and stem quality in *Pinus radiata* provenance trials established in the Marmara and Black Sea regions. *Doga Bilim Dergisi, D2 (Tarim ve Ormanlik) 7(1)*: 71–7.

SNEDECOR, G.W.; COCHRAN, W.G. 1967: "Statistical Methods", sixth edition. Iowa State University Press, Ames, Iowa, USA.

TURVEY, N.D.; RUDRA, A.B.; TURNER, J. 1986: Characteristics of soil and productivity of *Pinus radiata* (D. Don) in New South Wales; I. Relative importance of soil physical and chemical parameters. *Australian Journal of Soil Research 24(1)*: 95–102.

VARELIDES, C. 1995: Provenance variation in *Pinus muricata* on two sites in northern Greece. *Silvae Genetica 44(2–3)*: 129–31.

———1977: Site provenance interactions for three coniferous species in Greece. D.Phil. thesis, University of Oxford.