EARLY RESULTS OF PROVENANCE STUDIES ON Pinus muricata IN NEW ZEALAND

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ABSTRACT

Provenance trials of bishop pine (Pinus muricata) *were planted in 1972 and 1973. The 1972 trial, which compared seedlots of all ten native Californian populations and from four New Zealand stands, was planted at a single low altitude site, Rotoehu. The 1973 trials tested only the two northernmost native "green", two native "blue" provenances, and three New Zealand seedlots, and included* P. radiata *and a coastal Washington provenance of* P. contorta *as controls. These trials were planted on ten sites in both islands, mostly at altitudes over 500 m. Assessments were made when the trials were aged six and five years, respectively, from planting.*

At Rotoehu the Sonoma "green" provenance grew best, followed by San Luis Obispo (green), Monterey (green), Mendocino (blue) and Marin (green). The good early growth of some southern green provenances was largely offset by inferior straightness and needle retention, and signs of reduced current growth rate. Consideration of all traits as well as unpublished pollen phenology data indicated that in New Zealand the notorious green stands came from Marin County and the much superior blue stands from Mendocino County.

Growth in the 1973 trials was clearly slower at higher altitudes. At five of the ten sites a P. muricata *seedlot outgrew* P. radiata*; growth at these South Island sites was usually slower though at Golden Downs growth was relatively good. In the North Island only at Makahu (altitude 1030 m) did the growth of* P. muricata *exceed that of* P. radiata. *The Sonoma green provenance was the fastest growing* P. muricata *provenance at almost all sites.*

It was concluded that P. muricata *has promise on upland South Island sites and that Sonoma green and Mendocino blue are the best two provenances, though more reliance would be placed on Mendocino blue at this stage following 75 years' experience with this provenance. Future seed supplies of the Sonoma green provenance in New Zealand are being ensured*

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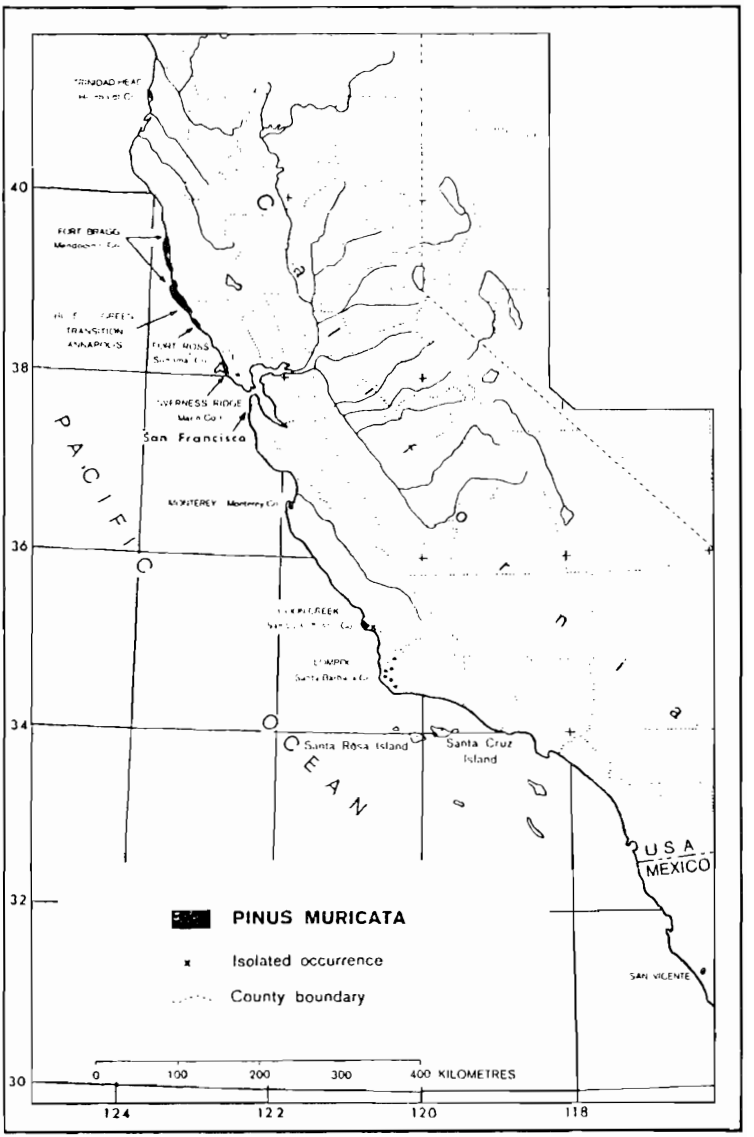
by planting seed stands and the continued availability of seed of the New Zealand blue provenance (originally Mendocino) will be maintained from existing and additional seed stands.

INTRODUCTION

New Zealand is now committed to *Pinus radiata* as its main plantation species. Nevertheless, in the last 25 years trials have been undertaken with many other conifers to identify species and provenances which grow well, produce acceptable wood and which could substitute for *P. radiata*. On sites suitable for production forestry none have promised to match *P. radiata* in both growth rate and timber properties. Recently several studies have been established with eucalypts of the Ash group which show promise of equally rapid growth, but most appear to lack the stability of performance over a wide range of micro- and macro-sites shown by *P. radiata*.

Bishop pine, *Pinus muricata*, has been planted in small quantities in State forests and in shelterbelts since the end of the last century. Up to 3000 ha were planted but of this only 200 ha were of a recognisably superior strain with blue-tinted foliage. This grew faster with straighter stems and less malformation than the majority, which had green needles. Over the years a few discerning foresters were aware of the potential of the blue provenance of this species in New Zealand but it was not until 1970 that much research was conducted on *P. muricata*. Many studies were completed then on the growth and wood properties of existing stands, mostly dating from 1925-35 (summarised in Shelbourne, 1974), and these showed that the best *P. muricata* stands of the blue provenance had yields and wood properties quite similar to those of *P. radiata*.

In exploratory work on monoterpenes, Williams and Bannister (1962, and unpubl.) found that trees known in New Zealand as "blue muricata" and "green muricata" were characterised by quite different turpentine composition. Forde and Blight (1964) and Mirov *et al.* (1966) confirmed and extended this work by surveying the natural populations, and were able to recognise three or four chemical races. In a comprehensive survey of New Zealand stands (unpublished data) wood turpentine composition was used as a prime criterion to determine the provenances. Only two races were found, which corresponded with the earlier report by Williams and Bannister (1962): one was distinguished by blue foliage with α-pinene predominant, and the other by green foliage with Δ-3-carene predominant.



From CRITCHFIELD, W.B. and LITTLE, E.L. 1966. Geographic distribution of pines of the world. USDA Forest Service Miscellaneous Publication 991, Washington, DC.

FIG. 1: *Distribution of* Pinus muricata *D. Don.*

The New Zealand blue provenance with predominant α-pinene must have come from either the Mendocino County or the Humboldt County populations in coastal California (Fig. 1), whereas the New Zealand green provenance must have come from either the Sonoma, Marin or Monterey County population.

Comparative studies of existing stands of *P. muricata* with *P. radiata* (Shelbourne, 1974) showed that in Kaingaroa Forest Cpt 1217 at the same stocking of 240 stems/ha and at age 45 years, heights of blue and green provenances were respectively 43.0 and 34.4 m, with total standing volumes of 948 and 613 m^3/ha, and mean diameters of 59 and 52 cm. These stands compared with *P. radiata* of similar stocking in the same part of the forest near Murupara (altitude 210 m), which had a mean height of 49.7 m, mean diameter of 59 cm and mean volume of 1117 m^3/ha. These results were fairly typical of comparisons made between *P. radiata* and blue *P. muricata* at advanced ages; *P. muricata* grew more slowly, especially in height when young, but ultimately reached similar diameters. However, it frequently carried heavier stockings, and sometimes higher standing volumes with less mortality than *P. radiata.*

Two series of provenance experiments were established at about this time by M. H. Bannister and C. J. A. Shelbourne. Bannister's study was planted in 1972 at a warm, low-altitude site, Rotoehu (coastal Bay of Plenty), to compare all the 10 native populations of *P. muricata* on a site where they could all be expected to thrive. The experiment was also planned to estimate the amount of genetic variation in different traits within populations (not reported on here) by planting 15 wind-pollinated families of each and to provide a pool of genetic variability for the species from which tree breeders could draw. Shelbourne's experiments involved only the two northern green provenances (from Sonoma and Marin) and the two native blue populations in most cases compared with *P. radiata* and *P. contorta* on a variety of mostly higher altitude sites (> 500 m) in both islands. New Zealand population samples of both green and blue provenances were included in both Bannister's and Shelbourne's experiments for the important objective of identifying the exact origin of existing New Zealand stands.

DESIGNS AND METHODS

Bannister's Rotoehu Experiment (Experiment A)

This experiment was planted on a low-altitude site at Rotoehu in the Bay of Plenty (Table 1). Entries consist of 15 wind-

TABLE 1: INFORMATION ON 11 SITES OF VARIOUS *P. MURICATA* PROVENANCE TRIALS

NZFS Plot No.	*Exper.*	*Forest*	*Cpt*	*Lat.*	*Alt. (m)*	*Topography*	*Slope (°)*
R 1025	A	Rotoehu	10	37° 52'	150	Rolling	0-20
R 388	B	Kaingaroa	1038	38° 21'	500	Flat	0
R 389	B,C	Kaingaroa	885	38° 43'	620	Flat	0
WN 232	C	Karioi	74	39° 25'	1020	Sloping	3
WN 230	C	Kaweka	93	39° 25'	790	Rolling	4
WN 231	C	Makahu		39° 11'	1030	Steep	20
N 257	C	Golden Downs	329	41° 35'	640	Steep	22
WD 150	C	Mahinapua	12	42° 45'	60	Flat	0
C 454	C	Hanmer, Jollies Pass		42° 30'	820	Sloping	11
S 247	C	Berwick, Trig "H"		46° 03'	580	Sloping	5
S 411	C	Naseby	17	45° 00'	760	Steep	20

pollinated families from trees randomly selected in each of the Californian stands (Table 2, Fig. 1). There are ten disjunct native populations of the species altogether including seven on the coast of California, two on the Channel Islands of Santa Cruz and Santa Rosa, and one at San Vicente in Baja California (Mexico). Two sets of 15 families were collected on Santa Cruz Island, one from trees with the typical prickly cones of *P. muricata*, and the other from trees with smooth cones, typical of the so-called *Pinus remorata* Mason. Also included were 15 families from each of two green and two blue provenance stands in Kaingaroa, and the Cedros Island population of *P. radiata* (which was planted in this, rather than a neighbouring *P. radiata* provenance experiment as it was expected to grow more slowly than other *P. radiata* provenances). These 236 families were planted as two randomised row plots of four trees each in each of the two replications, at a spacing of 5.5 × 5.5 m. A maximum of 16 trees per family were planted of which an average of 11 survived for measurement.

The following traits were assessed in September/October 1978 when the trial was six years from planting: height (dm), diameter b.h. (mm), stem straightness (rated 1 = crooked to 9 = straight), branch habit (rated 1 = uninodal to 9 = multinodal), malformation (rated 1 = multiple forks to 6 = no forks or ramicorns), coning (1 = none, 2 = few, 3 = many), dieback (1 = severe to 6 = none) and needle retention (1 = less than one year's needles, to 6 = three years' needles or more retained). Individual tree volumes (dm^3) were calculated from $V = 0.00003977$ $diameter^2 \times height$.

An analysis of variance was carried out on plot means (from one to four trees) and within-plot variance was estimated in a separate analysis. Provenance means were estimated by pooling data from the 15 individual families, with an average total of 154 trees per provenance.

Shelbourne's Experiments

Seedlots were sown unreplicated at FRI nurseries in Rotorua and Rangiora in December 1971 and 2/0 stock was raised for planting in July to August 1973.

Experiment B

This experiment examined variation between subpopulations, between provenances, and between some interprovenance hybrid families at two sites in Kaingaroa, Compartments 1038 and 885,

TABLE 2: COMPARISON OF *PINUS MURICATA* PROVENANCE MEANS — EXPERIMENT A, ROTOEHU, AGE 6 YEARS

Provenance	*Height (dm)*	*Diam. (mm)*	*Bole Volume (dm^3)*	*Straightness (1-9)*	*Branch Habit (1-9)*	*Malformation (1-6)*	*Cones (1-3)*	*Dieback (1-6)*	*Needle Retention (1-6)*
P. muricata — blue strain									
Trinidad (Humboldt Co.)	55	108	28	6.5	5.0	4.8	1.7	5.1	3.9
Mendocino	70	133	53	6.5	4.5	5.1	1.7	5.6	4.9
P. muricata — green strain									
Sonoma	76	156	78	6.0	4.6	4.9	1.6	5.5	5.1
Marin	62	133	47	6.0	5.4	5.0	2.2	5.5	4.9
Monterey	69	137	55	5.4	5.6	4.6	2.8	5.3	4.0
San Luis Obispo	76	136	63	5.1	5.2	4.8	2.1	5.4	3.7
Santa Barbara	66	129	47	4.4	5.1	3.9	2.7	5.1	3.6
Santa Cruz ("Remorata")	66	129	48	3.7	4.0	4.3	2.1	4.8	3.2
Santa Cruz ("Muricata")	68	131	50	3.5	4.3	4.0	2.1	4.7	2.9
Santa Rosa	54	104	25	4.6	3.8	4.7	2.5	5.3	3.2
San Vicente	65	124	43	5.0	3.2	3.5	1.3	5.1	4.3
Kaingaroa Cpt 1118) Blue	71	137	56	6.7	5.3	5.3	2.0	5.7	5.2
Kaingaroa Cpt 1117) strain	74	137	59	6.7	5.1	5.4	1.9	5.7	5.0
Kaingaroa Cpt 1234) Green	67	138	53	6.1	6.0	5.1	2.5	5.5	5.2
Kaingaroa Cpt 1217) strain	66	134	51	6.2	6.1	5.5	2.6	5.7	5.0
P. radiata — Cedros Is.	77	152	76	6.0	4.6	4.3	1.6	5.5	4.0
LSD (.05)[1]	3.4	8.4	8.3	0.5	0.5	0.4	0.2	0.4	0.3
F-test[2]	29.4**	17.5**	21.3**	33.1**	18.1**	15.3**	31.3**	5.7**	48.3**

1. Least significant difference = MS(pooled remainder/53.1) × 2 × 2
2. F_{15835} = MS(provenances)/MS(pooled remainder)

both of which were flat and experienced severe out-of-season frosts. Thirty-eight seedlots were planted at 4 × 2 m spacing at each site with from four to eight replications of six-tree row plots. The experiments were analysed as completely random designs because of large numbers of missing plots and only the provenance means, not those of families and subpopulations, are discussed here.[1]

Experiment C

Nine bulked seedlots including two native blue provenances from Humboldt and Mendocino Counties, two green populations (Sonoma and Marin), two New Zealand blue and one green as well as *P. radiata* and *P. contorta* were planted at nine, mostly higher altitude sites (Table 1) in a randomised block layout with six replications of 10-tree row plots at each. Mahinapua, a low altitude, wet "pakihi" site in Westland, was included as it is a "problem" site for *P. radiata*. Two seedlots (Sonoma green, 304 and Kaingaroa blue, 305) were omitted at Naseby and Mahinapua because of shortage of stock.

Two overall analyses of variance were carried out, for seven seedlots at nine sites and for nine seedlots at seven sites.

The following characters were assessed in Experiments B and C between May and November 1978 when the experiments were aged five years from planting: height (dm), diameter (mm) at 25 cm above ground, stem volume ($V = 0.00003927 \times \text{diameter}^2 \times \text{height}$), and stem malformation (1 = multiple forks to 6 = no malformation). Frost malformation and coning were scored in Experiment B only, as 1 = severe frost malformation, 2 = slight, 3 = unmalformed in lower 25 cm of stem, and coning as 1 = none, 2 = few, 3 = many.

RESULTS

Bannister's Rotoehu Experiment A

Differences between provenances in all traits were highly significant ($P < 0.01$), and except in the case of dieback were large, showing some clear patterns of provenance variation (Table 2). The native populations varied widely in growth rate; provenances from Santa Rosa Island and Humboldt County, respectively, near the southern and northern extremities of the

1. Complete, unpublished data on Experiments A, B and C available on request.

species' range grew slowest (mean volume per tree 25 dm^3), and the fastest-grown provenance was a "green" one from Sonoma County (78 dm^3). The San Luis Obispo provenance had grown as fast in height as Sonoma and ranked second in volume, with Monterey and Mendocino populations ranked third and fourth. It seems unlikely, however, that the early growth performance of the San Luis Obispo provenance will be maintained. Provenances from Monterey southwards show poor needle retention, slower recent growth and generally appear less healthy than the northern provenances.

Amongst the Kaingaroa (New Zealand) populations, the offspring from the two blue stands, Cpts 1118 and 7, grew a little faster than the Mendocino populations, and with volumes about double that of the Humboldt population; it can be safely assumed that they are derived from the Mendocino population. The growth of the two green populations, from Cpts 1234 and 1217 Kaingaroa, suggests they originated from either the Marin or Monterey population and definitely not the Sonoma population.

There are large differences between provenances in bole straightness and branch quality. The Humboldt and Mendocino blue provenances (and the two from Kaingaroa) are the straightest and Sonoma, Marin and the Kaingaroa green populations ranked second. These populations are all straighter than Monterey and other southern provenances. The Kaingaroa green populations have the highest branch habit scores (most multinodal) and correspond closely with Marin and Monterey, but not with Sonoma which has a much lower score.

Sonoma (and Mendocino and the Kaingaroa blue populations) show less coning than Marin, Monterey and the Kaingaroa green population (and most of the southern provenances). Mendocino, Sonoma and Marin provenances (and the Kaingaroa green and blue populations) all show much better needle retention than Monterey and the other southern provenances. Considering all these traits, it is clear that Marin County rather than Sonoma or Monterey is the likely origin of the Kaingaroa green stands.

In view of the known superiority of the local (Mendocino-derived) blue provenance in New Zealand over the local green, the Sonoma population's considerable superiority in volume over the Mendocino population at the Rotoehu site is of great interest. Although slightly poorer in straightness than Mendocino, Sonoma is much the same in its other morphological characters. At this stage it must be regarded as the best provenance on this warm, low-altitude site, though its long-term potential is still untested.

The height and diameter of *P. radiata* from Cedros Island were the same as those of the top-ranked Sonoma provenance of *P. muricata.* Their diameters were also similar to that of the Guadalupe Island population of *P. radiata* which is growing in a neighbouring *P. radiata* provenance experiment planted the same year also at 5.5 m spacing (unpublished data). The Guadalupe provenance in that experiment has a diameter which is 30% less than that of the mainland provenances of *P. radiata,* from which New Zealand *P. radiata* is derived.

Shelbourne's Experiments

Experiment B

There was considerable variation between the families and small subpopulation seedlots within the different provenances and these were averaged to give the provenance group means shown in Table 3. The Sonoma County control pollinated blue × green crosses grew the fastest. These crosses were made by W. B. Critchfield between trees of the green and blue races growing close to the transition zone at Annapolis. However, controlled crosses amongst the same blue parents grew very nearly as fast, and faster than the Fort Bragg seedlot, the average of five other Mendocino County seedlots or the combined New Zealand blue seedlots. The Sonoma County green population was growing marginally faster than the Mendocino blue population and the Marin and Kaingaroa green populations.

TABLE 3: COMPARISON OF 10 GROUPS OF *PINUS MURICATA* FAMILIES FROM DIFFERENT PROVENANCES AT TWO SITES IN KAINGAROA — AGE 5 YEARS (EXPERIMENT B)

	Blue/ Green Strain	*Height (dm)*	*Diameter (mm)*	*Vol. (dm^3)*
Trinidad Head (Humboldt Co.)	B	28	43	2.6
Ft. Bragg (Mendocino Co.)	B	35	58	6.3
Mendocino Co. (5 sub-pops)	B	35	56	5.6
Kaingaroa Cpt 1118 and Ashley	B	34	58	5.6
Sonoma Co. (blue × green crosses)	B × G	40	68	8.8
Sonoma Co. (blue × blue crosses)	B	39	67	8.1
Sonoma Co. (3 sub-pops)	G	37	63	7.0
Sonoma Co. (10 sub-pops)	G	36	62	6.9
Inverness (Marin Co.)	G	33	62	5.9
Kaingaroa Cpt 1054	G	31	55	4.6
Average LSD — Family groups		2.1	4.5	1.27

TABLE 4: HEIGHT AND VOLUME GROWTH OF *P. MURICATA* (7 SEEDLOTS) COMPARED WITH *P. RADIATA* AND *P. CONTORTA* AT 9 SITES (EXPERIMENT C)

Seedlot	*Origin*	*Kaingaroa Cpt 885*	*Makahu*	*Kaweka*	*Karioi*	*Golden Downs*	*Hanmer*	*Berwick*	*Naseby*	*Mahina-pua*	*Seedlot Means*
1. HEIGHT (dm)											
301	Trinidad, Humboldt Co.	23	11	18	14	30	12	15	16	26	18
302	Ft. Bragg, Mendocino Co.	27	13	21	18	35	13	16	19	30	21
303	Inverness, Marin Co.	27	12	21	15	29	13	15	19	27	20
304	Sonoma Co.	30	12	23	17	32	14	17	19*	27*	21
305	Cpts 7 & 1118, Kaingaroa	30	13	23	16	35	13	17	19*	27*	21
306	Cpt 4 Ashley	29	13	24	18	31	12	16	18	29	21
307	Cpt 1054, Kaingaroa	27	13	21	16	29	12	15	17	21	19
308	P. radiata R68/833	36	12	27	20	33	12	14	17	32	23
309	P. contorta Cpt 244 K'roa	30	11	8	13	30	15	17	19	17	18
	Site means	29	12	21	16	32	13	16	18	26	
	Average LSD (dm)	2.0									
2. VOLUME (dm^3)											
301	Trinidad, Humboldt Co.	1.2	0.3	1.6	0.6	1.9	0.2	0.6	0.8	3.1	1.1
302	Ft. Bragg, Mendocino Co.	2.9	0.5	3.0	1.1	3.4	0.4	0.7	1.1	3.8	1.9
303	Inverness, Marin Co.	2.8	0.5	3.5	1.0	2.2	0.5	0.8	1.3	3.7	1.8
304	Sonoma Co.	4.1	0.5	4.0	1.4	2.9	0.5	0.8	1.5*	3.6*	2.2
305	Cpts 7 & 1118, Kaingaroa	2.9	0.6	3.3	0.9	3.2	0.3	0.8	1.1*	3.3*	1.8
306	Cpt 4 Ashley	3.3	0.6	4.1	1.3	2.4	0.3	0.8	1.0	3.9	2.0
307	Cpt 1054, Kaingaroa	2.2	0.7	3.2	1.0	2.4	0.3	0.7	1.0	1.8	1.5
308	P. radiata R68/833	6.8	0.3	5.4	2.3	3.4	0.2	0.4	0.8	5.2	2.8
309	P. contorta Cpt 244 K'roa	2.0	0.2	0.1	0.3	1.3	0.4	0.7	0.9	0.6	0.7
	Site means	3.2	0.5	3.1	1.1	2.6	0.3	0.7	1.0	3.2	
	Average LSD (dm^3)	0.6									

*Provenance not planted, missing cell value calculated.

The slight superiority of the Sonoma green provenance echoes its excellent performance at Rotoehu. Differences between Marin, Sonoma and Mendocino populations were relatively small in these Kaingaroa experiments, possibly owing to a levelling effect of the severe setback from frost.

The marked superiority of the two groups of control-pollinated crosses over the other lots, and the poor growth of the Trinidad Head blue population are the only differences that stand out. It is likely that the superiority of the crosses is due to a reduction in the level of inbreeding by crossing trees from different stands. The slightly poorer performance of the New Zealand seedlots than the equivalent native populations is contrary to usual experience with other species and indeed with the results at Rotoehu.

Experiment C

The four northernmost native populations of *P. muricata* as well as two blue (ex Mendocino) and one green (probably ex Marin) New Zealand seedlots are compared with *P. radiata* and *P. contorta* of the Kaingaroa strain (originally coastal Washington) in these experiments at nine sites throughout New Zealand. Seedlot means at each site are shown in Table 4 and the results of the analysis in Table 5. Heights of the Ashley blue seedlot relative to those of *P. radiata* and *P. contorta* at each site are shown in Fig. 2.

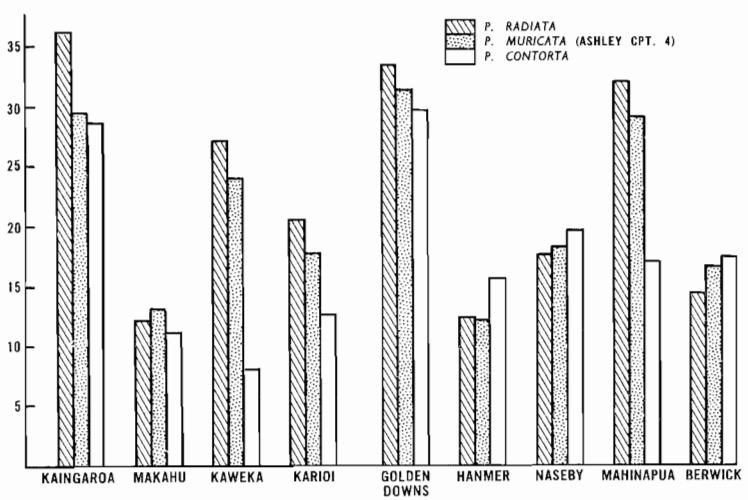


FIG. 2: *Height (dm) at age 5 years from planting (Experiment C).*

TABLE 5: VARIANCE COMPONENTS (AS PERCENTAGE OF TOTAL VARIANCE) FOR HEIGHT AND VOLUME OF 7 SEEDLOTS AT 9 SITES (EXPERIMENT C)

	Height		*Volume*	
Source of Variation	*% Total Variance*	*F Ratio*	*% Total Variance*	*F Ratio*
Sites	68.5		34.8	
Seedlots	2.1	3.5** [1]	6.5	5.5***
Sites × Seedlots	7.5	13.0***	12.2	10.8***
Reps in sites	1.8	4.5***	3.0	4.0***
Reps × Seedlots in sites	1.6	1.7***	2.7	1.6***
Within plot	18.5		40.8	
Average LSD	2.0		0.6	

[1]** $P < 0.01$
*** $P < 0.001$

At five of the nine sites, a *P. muricata* seedlot is outgrowing *P. radiata*; these sites (except Golden Downs) are usually the ones showing slower growth. This result has important implications as it is rare for any species to outgrow *P. radiata* in New Zealand. Although the age is five years the heights of *P. radiata* are still only between 1 and 2 metres at the poorer sites, while heights at the sites with faster growth were 3.6 m at Kaingaroa Cpt 885 and 3.3 m at Golden Downs. These growth rates contrast with a height of 6.4 m for *P. radiata* at the same age at Cpt 1350 Kaingaroa, altitude 410 m (unpublished data). In terms of tree size, the results obviously apply to very juvenile material.

It is evident in the South Island at Golden Downs, where growth was relatively good, that the better *P. muricata* provenances equal *P. radiata* in growth rate, whereas in the North Island at sites like Kaweka and Karioi, where the trees are smaller than at Golden Downs, *P. radiata* outgrows *P. muricata*. There seems to be some influence of latitude in this apparent interactive behaviour.

The analysis of variance (Table 5) reflects the changing of seedlot height and diameter ranking with site, evidenced by a highly significant seedlot × site interaction; the variance component for seedlots is half the size of the seedlot × site interaction component.

Height growth at the different sites was quite variable; it was best at the southern Kaingaroa site, altitude 620 m, in spite of serious frost damage in the first two years; Golden Downs ranked second, followed by Mahinapua and Kaweka. Growth at the other sites was very slow and was worst at Hanmer (820 m)

and Makahu (1030 m). In retrospect, more trials should have been planted and these should have been located at intermediate altitudes of 400 to 600 m in the North Island and 200 to 500 m in the South Island.

Amongst the *P. muricata* provenances, the Trinidad Head population is growing slowest, though its performance is relatively somewhat better in the South Island. The Sonoma green provenance is the fastest-grown native population at all but one site, and the New Zealand green seedlot has grown slower than any others except Trinidad. Its growth is more in line with that of Marin than Sonoma.

Differences between provenances in malformation were not significant.

CONCLUSIONS

These trials are still too young and the trees too small for confident predictions and recommendations to be made about the performance of the *P. muricata* provenances relative to *P. radiata.* However, they are providing a growing body of information which ultimately will provide some guidelines for provenance and species siting.

At Rotoehu, Experiment A contains the full complement of provenances of *P. muricata* and allows an examination of the forestry potential of them all, albeit under conditions where *P. radiata* is clearly much better adapted and faster-growing. At this stage it is probably safe to reject the southern green provenances (from Monterey southwards) from further serious consideration on the basis of their inferior tree form, growth rate and general health. Comparison in this and the other experiments between the New Zealand green seedlots and the native provenances, supported by recent pollen phenology data (unpublished) lead to the conclusion that the New Zealand stands originated from the Marin population. This information, taken in conjunction with comparisons of originally Mendocino blue and Marin green provenances in mature stands in New Zealand which underline the extreme inferiority of the Marin green stands (Shelbourne, 1974), narrows the list of candidates for "best provenance" down to Sonoma green and Mendocino blue. The superiority in growth rate of the Sonoma provenance at Rotoehu and to a lesser extent elsewhere, is offset at this stage by the excellent long-term performance of the Mendocino blue population. Stem straightness of this population is also marginally

superior and branch habit is slightly more multinodal than that of Sonoma. The early performance of the northernmost Humboldt blue population is disappointing, though there is evidence from the A.C.T., Australia, in a 1950 planted provenance trial that at age 23 years it nearly equalled the Mendocino blue population in growth (Doran, 1974).

The results from Experiments B and C at the central (Cpt 1038) and southern Kaingaroa (Cpt 885) sites show that the best blue *P. muricata* is susceptible to severe out-of-season frosts, in this case in March following August planting, and that it recovers from frosting less well than *P. radiata,* which is outgrowing it in height by about 20% at Cpt 885 and by a lot more at Cpt 1038. These trials show slightly better growth by the Sonoma green than by other *P. muricata* native populations, and fastest growth of all by controlled crosses between Sonoma green and Mendocino blue trees.

The comparison of the growth of *P. muricata* provenances with *P. radiata* and *P. contorta* at nine mainly higher altitude sites should help formulate future recommendations regarding planting the species. However, growth has been so slow at many of these sites that, with heights of 1 to 2 m by age five years, the trees are not big enough for one to make reliable predictions about future growth; by age 12 years, following canopy closure, this should be possible. In the meantime, these early results show quite small but consistent differences between the *P. muricata* provenances; Humboldt is the slowest and Sonoma the fastest, followed by Mendocino blue. At all South Island sites over 500 m altitude, *P. muricata* matches or exceeds the growth of *P. radiata,* in marked contrast to the situation in the North Island where only at Makahu, altitude 1030 m, does *P. muricata* outgrow *P. radiata* at this age.

From previous investigations in stands planted in 1925, even in the lower altitude parts of Kaingaroa (210 m), volume growth of *P. muricata* of Mendocino origin in mature stands is little inferior to that of *P. radiata,* so it is probably too early to reject *P. muricata* from consideration for higher altitude sites in the central North Island. Its capacity to carry high basal areas without much mortality is certainly an attractive feature. It is, however, not well adapted to sites subject to severe out-of-season frosts.

It would be worth while at this stage to make regular small commercial-scale plantings of the New Zealand Mendocino blue provenance in South Island forests over 500 m in altitude, to

gain experience in handling the establishment and silviculture of this species. Further experimental planting should also be carried out at lower altitude sites in both islands with Mendocino blue and Sonoma green provenances to provide growth data on a range of sites so that the environmental adaptation of these provenances relative to *P. radiata* can be clarified.

No commercial quantities of seed of the Sonoma population are available and collection would be difficult (Eldridge, 1979) though further small quantities could be obtained for experimental purposes. Some 10 000 seeds from Sonoma County have been provided by K. G. Eldridge (Division of Forest Research, CSIRO, Canberra) which was collected from 30 trees distributed along the entire north-south extent of the coastal Sonoma population. Most of this seed has been sown to plant a combined seed production and selection stand in 1981 on a site with good growth and cone production. Following a future assessment of the trials reported here at age 12 years a clonal seed orchard could be established of the Sonoma population by grafting clones selected in the trials, where offspring from a total of 54 trees are growing.

Some additional seed stands of the Mendocino blue population should be developed to act as seed sources in the immediate future. Existing approved seed stands are at Ashley Cpt 4 (10.8 ha, 1947), Kaingaroa Cpt 1118 (38 ha, 1925) and Kaingaroa Cpt 7 (7 ha, 1949). These account for nearly the whole area of the blue provenance over the age of 15 years. Collection of seed is difficult in these stands, and in the case of Cpt 1118 Kaingaroa would only be practicable after felling.

Considerable areas of specially collected seedlots from the Mendocino and Humboldt Co. populations, were planted in several conservancies in 1975 and 1976 both as potential seed sources and for selecting trees for breeding populations. These should be developed as seed stands in the future as the need arises. In the meantime the only stands that are of suitable age for immediate seed production appear to be at Golden Downs, and immediate action should be taken to develop these as seed stands.

Wind-pollinated progeny tests of 35 select trees of the New Zealand blue population were planted at Cpts 885 and 1038 Kaingaroa, and at Karioi in 1973. Assessment of these at age 10 to 12 years should allow selection of the best trees from the better families from which clonal seed orchards could be propagated. A further assessment of the experiments described

here will be made at the same time and recommendations should be made then, based on the relative merits of the Mendocino blue and Sonoma green populations, as to the further development of improved seed supplies of these two provenances, and on the extent of conservancy planting of the species.

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