RECENT INVESTIGATIONS OF WOOD PROPERTIES AND GROWTH PERFORMANCE IN *PINUS MURICATA*

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SYNOPSIS

There is a need in New Zealand for an exotic tree species which is better adapted than Pinus radiata *to colder, higher-altitude sites and poorer soils but with similar growth rates and utilization characteristics and with good form.* Pinus muricata *of the northern blue-foliaged provenance promises to meet these requirements better than any other species. Most muricata pine planted in New Zealand has been of a more southerly green-foliaged provenance and this is in all respects much inferior to both radiata and blue muricata. This paper reviews the results of recent utilization studies and several comparisons of growth of the blue provenance of muricata and radiata in stands of various ages in New Zealand*

Identity of races in New Zealand has been confused but this has now been resolved by turpentine analysis, and it is almost certain that the local blue provenance comes from Mendocino county.

Blue-foliaged provenances proved to be much more frost-tolerant than either the green-foliaged provenances or radiata in a Californian experiment. Muricata has the same adult resistance to Dothistroma pini *needle blight as radiata.*

Nursery characteristics of blue muricata are generally very similar to radiata, though there are twice as many seeds per kilogram and seedling heights are about 20% less.

Wood density in muricata shows a much smaller pith-to-bark density gradient than radiata though whole-tree density of both species is similar. The contrast between springwood and summerwood density in muricata is greater than in radiata, giving a less even-textured wood. Clear-sample strength properties of dry wood of muricata are appreciably better than radiata's. Resin content of heartwood in muricata is double that in radiata, but is much the same for the sapwood. The papermaking properties of blue muricata are generally good and similar to radiata's.

A timber grade study sawn mainly to 10 × 5 cm scantlings gave better visual grades than with comparable logs of radiata, and the average stiffness measured by machine stress grading was higher for muricata (4.97 × 10^3 pascal) than radiata (4.27 × 10^3 pascal).

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Comparative studies of growth of blue muricata and radiata in stands of the same age on normal radiata sites below 600 m altitude showed that the height of muricata averaged 85% of radiata's. However, on the few higher-altitude sites with blue muricata plantings, its height exceeded that of radiata by 17 to 28%. Bole straightness was consistently superior in muricata, the amount of forking was similar in both species, the frequency of uninodal trees was higher in muricata, but branch diameters were slightly greater for a given stocking. In the two cases where stocking of both species was about the same, the stem diameters were also the same. In a comparison of green and blue muricata with radiata on the same site in Kaingaroa at age 45 years, total volume of neighbouring stands was 610, 950 and 1120 m^3/ha, respectively, with similar stockings of about 250 stems/ha.

INTRODUCTION

Any species considered for large-scale production forestry in New Zealand must inevitably be compared with *Pinus radiata*. It should have equally rapid growth, tolerance of a wide range of sites, and utilization characteristics either equal to or complementary to those of radiata. A slower-growing species could be acceptable if it had more valuable timber or a wider tolerance of sites or pathogens than radiata.

Few species meet these criteria. Douglas fir has too specialized end uses, slower growth, and needle cast disease *(Phaeocryptopus gaeumannii)*, while its site requirements almost coincide with those of radiata. Corsican and ponderosa pines, although more frost-tolerant than radiata, are seldom planted now because of their slow growth and life-long susceptibility to *Dothistroma pini* needle blight.

Sites with low ambient temperatures, snow and extreme frosts, and adverse soil conditions, which are too exacting for even radiata, are a problem. The limits of radiata's tolerance of these conditions are poorly defined, and till now there has been little pressure to afforest such sites. In future, however, they will almost certainly be used to produce the highly concentrated timber resources needed by large industries.

Although genetic variation occurs among and within populations of radiata there is no evidence that any of the natural populations is better adapted than local stock to most of the problem sites in New Zealand (Burdon and Bannister, 1973). Selection and breeding for cold-resistance within these populations could be undertaken, but it would be long term, costly, and with uncertain effectiveness.

The present candidate for cold, frosty sites is *Pinus contorta*, although there is little recent silvicultural experience with this species. It is known to have a fast early growth rate and to be very frost-hardy, but it will give far smaller piece sizes and lower productivity. It is unlikely that it could be processed and used as if it were radiata. Moreover, it is extremely prone to opossum damage.

The only likely species for such sites is *Pinus muricata,* a native of the Californian coast of the United States where it is commonly known as bishop pine. With radiata pine and *P. attenuata* it forms the well-defined sub-group of the Californian closed-cone pines. Muricata is found in eight coastal populations, six of which are disjunct, and on the islands of Santa Cruz and Santa Rosa (Lindsay, 1932). It occurs between latitudes 31° N at San Vicente in Mexico to 41° N at Trinidad Head. By contrast, radiata pine is found on the mainland coast in three areas from 35° 30′ to 37° N and also on Cedros and Guadalupe Islands at latitudes 28° and 29° N.

It was known that at least two provenances* of muricata had been planted in New Zealand and that the northern race with glaucous foliage, commonly called the "blue strain", was superior in growth and form to the more widely planted "green strain". Foliage colour was, however, an unreliable means of identification except where the races were planted side by side. Shelbourne *et al.* (1973) used differences in monoterpene composition between provenances in a countrywide survey of muricata stands to identify their race. The areas of the blue race were found to total only about 200 ha (see Table 1) and appeared to derive from a single importation of seed in about 1903. Blue muricata is doubtless present also in occasional shelterbelts, amenity plantings, and small areas in State forests.

Three years ago, little information was available from New Zealand or elsewhere concerning the relative growth rates of muricata and radiata and the utilization characteristics of muricata. We needed to know how the growth rates of the two species compared over a range of site conditions, preferably covering the extremes, and also whether the utilization characteristics of muricata would allow it to be processed and marketed along with radiata. Investigations were therefore started in several research fields at the Forest Research Institute. In one investigation reported here, data on growth were collected from stands of the "blue" provenance by various methods and by various agencies including the Forest Research Institute, local New Zealand Forest Service staff, and one private concern. Neighbouring stands of radiata planted in about the same year were sampled in the same manner to obtain comparative data.

Many studies on utilization characteristics have also been completed and this paper reveiws information on the characteristics of blue muricata from every available source, including recent unpublished reports and personal communications.

*The term "provenance" is used to denote a population originally from a specific localtiy in California which retains this identity when grown for one or more generations in New Zealand. "Race" is used to mean a group of provenances — *e.g.,* the blue-foliaged provenances. Blue *strain* and green *strain* will not be used further.

TABLE 1: NEW ZEALAND STANDS OF "BLUE" (α-PINENE) RACE OF MURICATA

Conservancy and Forest	*Cpt*	*Area (ha)*	*Date of planting*	*"Green" contamination*
Auckland:				
Waiuku	16	8.9	1939	Moderate
Puhipuhi	—	2.4 (shelterbelt)	1905	Suppressed green trees on edge
Rotorua:				
Kaingaroa	7	6.5	1905-4 regen.	Slight/moderate
	1118	36.8	1925	Very slight
	1217	24.3	1926	Very slight
	1161	2.4	1925	Very slight
Nelson:				
Golden Downs	8, 9, 24, 25, 26, 27, 30, 31, 38, 46, 48, 53, 61, 62, 63, 74	107.0	1931-38	Naturally regenerated 1963-73.* Resin not yet sampled.
Canterbury:				
Hanmer	1, 9, 8, 40	Area not yet completely evaluated — mostly small stands and shelter-belts 1908 onwards.		
Ashley	14 (seed stand B7)	0.8	1946	Very slight
	4	0.4	1947	Very slight
Westland:				
Mahinapua	4	5.3	1927	Nil?
	10	2.4	1923	Nil?
Southland:				
Conical Hill	6 (shelterbelt)	1.2	1914	Nil?
	Total:	198.4 ha		

*D. A. Field (pers. comm.)

REVIEW OF OTHER WORK

Until recently, little has been written about muricata pine for use in plantation forestry, though the species has long interested botanists, taxonomists, and biochemists.

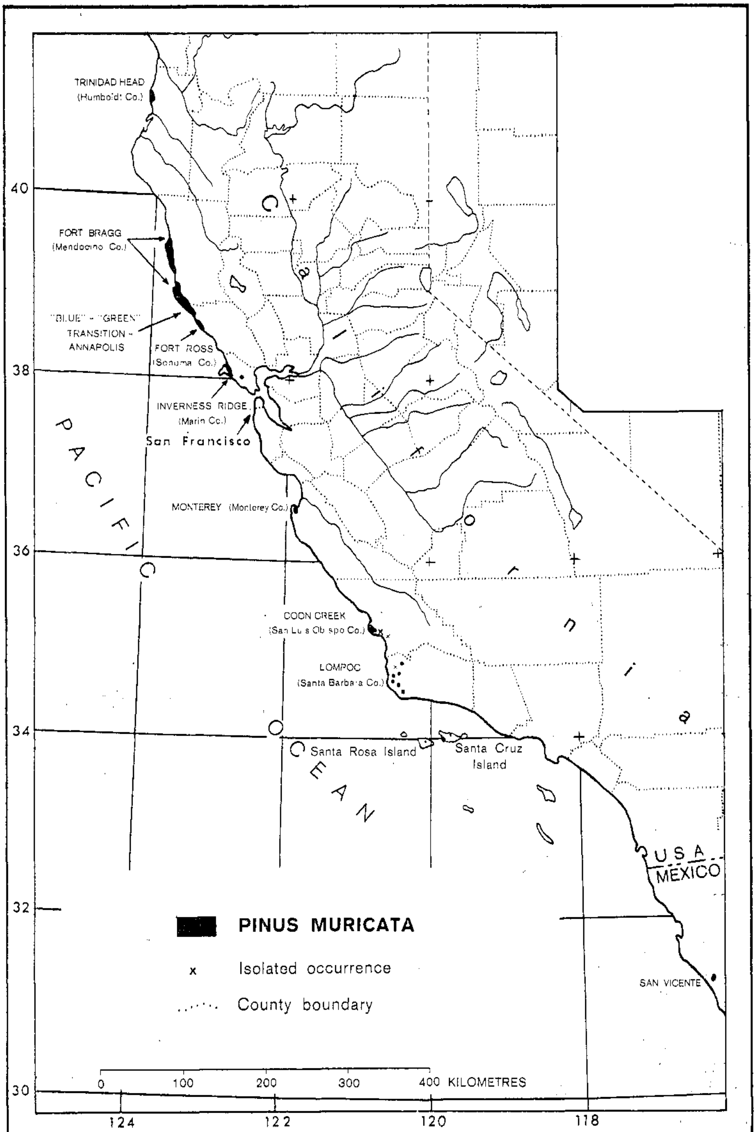
1. *Taxonomy, Distribution and Monoterpenes*

Lindsay (1932) comprehensively reviewed distribution, ecology, soils, and climates of the native stands as well as experience with this species in areas outside its natural habitat, including New Zealand. It is interesting to note that important provenance differences in muricata had already been observed in New Zealand at that time.

Duffield (1951) in his monograph on muricata pine divided the species into four varieties: *P. muricata* var. *borealis* characterized by bluish foliage, large size of trees, dense narrow crown, and rough bark; *P. muricata* var. *muricata* with green foliage, a spreading crown, and smoother bark; *P. muricata* var. *remorata* confined to Santa Cruz and Santa Rosa islands, and *P. muricata* var. *cedrosensis* confined to Cedros Island.

The distribution of the species is shown in Fig. 1. Apart from the stands in Sonoma and Mendocino counties, all the other populations are genetically isolated from one another. The Mendocino and Sonoma county stands, however, have a more or less continuous distribution along the coast from just north of Fort Bragg for about 120 km to Fort Ross. Near Annapolis, 85 km south of Fort Bragg, there is an abrupt transition over no more than 2 km from the blue-foliaged variety in the north to the green-foliaged one in the south. It should be noted that *P. muricata* var. *cedrosensis* has now been provisionally assigned to radiata pine (see below).

Duffield included stands at Trinidad Head and Fort Bragg in his var. *borealis* but was uncertain about the status of the next three populations southwards (that between Annapolis and Fort Ross, and those at Inverness and Monterey). Variety *muricata* included the remaining mainland populations, at San Luis Obispo, Lompoc, and San Vincente. However, Williams and Bannister (1962) discovered that the monoterpene composition of wood oleoresin from Monterey was radically different from that described by Mirov (1947) from Fort Bragg. This led to an investigation by Forde and Blight (1964) of monoterpene composition of resin samples collected from the lower boles in stands throughout the range of the species. Three very distinct chemical races among the mainland populations were revealed: a northern one with turpentine composed almost entirely of α-pinene, a central race with predominantly Δ-3-carene, and a southern race with mainly sabinene and terpinolene. The pines from Santa Cruz and Santa Rosa islands differ from this southern race in having α-pinene as a third major component. Mirov *et al.* (1966) made oleoresin collections from all the natural stands (in contrast to Forde and Blight who depended partly on provenance trial material from Canberra, Australia) and they also sampled the area in Sonoma county near Annapolis at latitude 38° 42′ N



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 muricata pine.*

where there is a change from blue- to green-foliaged trees. They established that the abrupt change from the northern α-pinene to the central Δ-3-carene race occurs at that point with a narrow transition zone where a few hybrid individuals are found with intermediate monoterpene composition.

Bannister (1972) has proposed that a new informal classification of muricata and radiata pines be adopted pending formal revision of the group. This divides radiata pine into five populations named after their localities, Ano Nuevo, Monterey, Cambria, Guadalupe and Cedros (thus grouping Duffield's *P. muricata* var. *cedrosensis* with radiata). Muricata is then split into a northern blue race (the two α-pinene populations north of Annapolis from Fort Bragg and Trinidad Head), a central green race (the three Δ-3-carene populations, from south of Annapolis to Monterey), a southern green race (the three sabinene-terpinolene populations from San Luis Obispo to San Vincente), and an island green race (the pines on Santa Rosa and Santa Cruz islands).

A survey of muricata pine stands in New Zealand (Shelbourne *et al.*, 1973) indicated that only central green (Δ-3-carene) and northern blue (α-pinene) races have been introduced into exotic forests. First-year height measurements in a provenance study (Shelbourne, 1973) indicate that the local blue α-pinene provenance most probably comes from the Mendocino County population, not from Trinidad Head in Humboldt County, and that the New Zealand Δ-3-carene provenance possibly comes from the Sonona County stands south of the blue-green transition rather than from Marin or Monterey counties.

2. *Provenance Experiments*

The only provenance experiment with muricata pine planted before 1968 was established by Fielding at Reid's Pinch near Canberra, Australia with six seedlots from the full latitudinal range of the species (see Table 2). A single 0.04 ha plot of each seedlot was planted. Mean heights and diameters at breast height for age 10 years (Fielding, 1961) and for 23 years (J. C. Doran, pers. comm.) are shown in Table 2. Heights and diameters of the three mainland provenances of radiata planted on the same site are shown for comparison.

The Reid's Pinch arborteum is located at latitude 35° 18′ S on a good-quality site previously carrying wet sclerophyll forest of *Eucalyptus fastigata* and *E. robertsonii* at an altitude of 970 m. The annual rainfall is 1020 to 1140 mm and it has a moderate winter snowfall. Fort Bragg was the tallest muricata provenance at ages 10 and 23 years, but after a slow start the Trinidad Head provenance is now only 0.5 m behind in height. At both 10 and 23 years, the Monterey and Ano Nuevo provenances of radiata had much the same height as the Fort Bragg provenance of muricata. In basal area, however, Ano Nuevo and Monterey radiata were inferior to Fort Bragg muricata.

Fielding also assessed various morphological characters of both species and found a decrease from north to south in

TABLE 2: HEIGHT AND DIAMETER IN SINGLE PLOTS OF MURICATA AND RADIATA PROVENANCES AT REID'S PINCH, A.C.T.

	10 years			23 years			
Origins	*No. of branch clusters*	*Height (m)*	*dbh (cm)*	*Height Predom.* (m)*	*dbh† (cm)*	*Stocking (stems/ha)*	*Basal area* (m^2/ha)
P. muricata							
Trindidad Head	21.6	6.46	11.0	18.4	21.5	1548	59.0
Fort Bragg	19.0	7.47	12.7	18.9	24.1	1387	65.2
Inverness	19.8	6.40	11.4	17.5	21.5	1613	62.6
Monterery	15.9	6.61	11.2	17.3	21.0	1161	42.6
Lompoc	16.1	5.85	11.4	17.1	24.6	1000	52.8
San Vincente	12.1	4.97	8.7	16.6	20.1	1129	40.6
P. radiata							
Monterery	15.6	7.53	11.7	20.1	20.5	1406	53.1
Ano Nuevo	16.8	7.13	11.6	20.4	20.6	1567	60.3
Cambria	13.4	6.71	10.8	18.6	18.8	1097	33.9

10 year data — from Fielding (1961).
23 year data — from J. C. Doran (pers. comm.).
*Defined as the mean height of 124 trees of largest outside bark diameter/ha.
†Internal trees only, excluding outer row.

number of branch clusters among the muricata provenances, from 21.6 clusters (age 10) in the Trinidad Head origin to 12.1 at San Vincente. For bole straightness, Trinidad Head was better than Fort Bragg which itself was much better than Monterey and Lompoc, though a little worse than Inverness Ridge.

Libby established provenance experiments with open-pollinated families of radiata and muricata near San Francisco at two locations in 1968, and experiments with the same material were planted by Brown and Eldridge in the A.C.T., Australia in 1969 and 1970, and by Bannister (1972) at Rotoehu in New Zealand. A series of progeny tests of New Zealand selected trees of the local blue provenance as well as provenance trials involving origins north of San Francisco have been planted on predominantly harder, high-altitude New Zealand sites in 1973 (Shelbourne, 1971).

Third-year heights from the Californian experiments (Libby, 1971) showed that the Humboldt County population was initially much slower-growing than the others, as has also been found in New Zealand.

In the winter of 1973 (at 5 years from planting), the Californian experiments were damaged by an unusual cold spell that included 7 to 10 days of freezing temperatures with a minimum of —8.3° C. J. V. Hood (pers. comm.) rated trees in one experiment for various types of frost damage and measured height and diameter. Under these conditions radiata in general suffered much worse cold damage than all the muricata provenances. Cambria and Cedros radiata provenances suffered worst, and Humboldt County and Mendocino County (blue) muricata were almost unaffected, followed by the island muricata. Height of the best radiata provenances was about 4.2 m compared with 1.9 and 2.7 m for Humboldt and Mendocino muricata, respectively.

3. *Susceptibility to* Dothistroma pini *Needle Cast*

Results of inoculation experiments, comparing susceptibility of radiata, muricata, and other pines of various provenances to *Dothistroma pini,* the needle cast disease, are inconclusive. Cobb and Libby (1968) reported that 1-year-old seedlings of radiata were highly susceptible and 2-year-old seedlings of blue muricata were resistant, with radiata from Guadalupe Island intermediate. Long (1971) compared 1-year-old seedlings of three mainland provenances of muricata with three provenances of radiata and could show no differences in infection between taxa. In New Zealand, muricata was compared with radiata, ponderosa, Corsican, and contorta pines when inter-planted with infected radiata. After 3 years all species were 100% infected and blue muricata was defoliated almost as severely as the worst species, ponderosa pine (J. W. Gilmour, pers. comm.). However, it is obvious in New Zealand that radiata and muricata, in contrast to Corsican and ponderosa pines, are not very susceptible after age 10 to 15 years and show little defoliation. Parker and Collis (1966) reported an average of 60% mortality in several 7-year-old radiata stands in Vancouver Island from *Dothistroma* compared with only 13% for muricata (provenance unspecified).

In a provenance comparison of *Dothistroma* susceptibility in Kaingaroa Forest, New Zealand, there was a clear indication at 2 years from planting that the blue provenances from Mendocino County were less infected and defoliated than green provenances from further south (J. W. Gilmour and C. Bassett, pers. comm.). There was a roughly clinal increase in the infection and defoliation scores of provenances from north to south. Infection percentages averaged 86 and 72 for Humboldt and Mendocino provenances, respectively, while the green provenances ranged from 91% for Sonoma to 98 to 100% for the remaining ones.

4. *Nursery Characteristics* (J. T. Miller and B. Swale, pers. comm.)

There are normally 66 000 to 77 000 seeds/kg of clean seed in muricata, compared with about half this number in local radiata. Over 90% germinate, and rate and evenness of germination are improved by stratification or a 24-hour cold soak. Muricata behaves in much the same way as radiata in the nursery and can be grown under the same regimes of spacing, chemical weed control, irrigation, and root wrenching. It is possible to grow satisfactory 1/0 stock at some warmer and/or more fertile nurseries for planting the following July to September, provided sowing is done in early September. However, in nurseries such as Milton, where 1/0 radiata stock is marginally big enough, muricata 1/0 will be too small. At nurseries prone to summer drought (*e.g.*, Rangiora), 2/0 stock sown in September is desirable, though 1½/0 with December sowing is satisfactory at Kaingaroa. On favourable nursery sites 2/0 muricata has been found to be too big. For the same conditions and same age, muricata plants will be about 20% shorter than radiata but with a thicker stem.

5. *Growth of Muricata Pine as an Exotic*

Weston (1957) summarized information available on New Zealand plantings of muricata, distinguishing between the green provenance ("a relatively slow-growing tree of poor form with short yellowish-green needles") and the blue provenance ("a tree of generally better form with longer bluish-green foliage"). At that time 2363 ha, mainly of the green provenance, had been planted, but much of this is now being felled.

In 1966, current knowledge of muricata pine was summarized in *FRI Symposium No. 7* (Weston, ed.). Lack of accurate knowledge of the provenance of different stands caused difficulties in interpreting growth data. The species was best understood in Canterbury Conservancy, but the opinions of New Zealand foresters were well represented by that from Rotorua Conservancy — "Present forester/user attitude is that the species is a dead loss. There are no plans for its future use." Bannister (1966), reviewing the available information on the species and the differences between provenances, concluded that although further testing of central and southern provenances would be pointless the northern blue provenances might be suitable for cooler and wetter parts of the South Island.

Poynton (1972) reviewed the performance of muricata in southern Africa and presented growth data from plantations throughout the Republic of South Africa, Rhodesia, and Malawi, although no provenance information was available. The best example of the species were found in the winter rainfall areas of the Cape province (around latitude 33° S). At Tokai, on the Cape peninsula, for example, a height of 30.5 m was reached at age 58 years, which came close to the growth of radiata in the same area. Growth and health were generally poor in the summer rainfall areas and there has been little further planting.

In Australia, N. B. Lewis (pers. comm.) reported that a few pre-1940 stands of green provenance exist but are of very poor form and slow-growing. Apparently there was one importation of seed of the blue provenance into Australia in about 1948 from Hanmer, New Zealand. This gave rise to small stands at Kowen (altitude 750 m) and Blue Range (altitude 870 m) near Canberra, A.C.T., one at Second Valley in the Adelaide Hills, and another at Mt Burr in South Australia. The last two sites were at low altitude. Growth data of radiata and muricata in these stands (Table 3) were provided by A. G. Brown, N. B. Lewis, and C. K. Pawsey, respectively. The stands of radiata and muricata had generally been thinned to different stockings, so the basal area figures are not comparable. In each area the two species had almost equal mean diameters. Heights of muricata, however, varied from 78% to 86% of those of radiata. On these sites, total volume production of muricata is also likely to be inferior to that of radiata. This is in contrast to the situation at Reid's Pinch, A.C.T., at 970 m altitude, where heights are about equal and basal area of muricata is superior.

Muricata pine does not appear to have been planted at all in France (J. F. Lacaze, pers. comm.), Turkey (E. N. Cooling, pers. comm.), Italy, or in the Mediterranean region in general (A. de Philippis, pers. comm.). Various ornamental and arboretum plantings, dating back to 1846, have been made in Britain and Eire. These have been recorded and measured by A. F. Mitchell (pers. comm.). There are no large-scale plantations and the only old group plantings known are a line of trees at Muckross Abbey, Killarney, planted about 1930, with height 27.4 to 29.0 m. These are of the blue provenance and seed collected from them was used to establish plots in 1960 at Bedgebury (Kent), Ystwyth (Wales), and Bere (near Southampton). At Bedgebury, Mitchell reports that on a very poor acid soil the better trees of blue muricata have an annual height growth of 1.8 m at age 11, which is more than neighbouring older radiata had at the same age. At Bere, the two tallest trees were 11.9 and 12.5 m tall with diameters of 21.1 and 22.6 cm at 13 years.

TABLE 3: MURICATA SAMPLE PLOT DATA FROM AUSTRALIA
(with radiata comparisons)

Forest and Species	Cpt	Age	Stocking (stems/ha)	Basal area (m^2/ha)	dbh (cm)	(m)	MABAI	MAHI	MAVI	M:R MABAI	M:R MAHI
Kowen, A.C.T.:											
Muricata	47	23	912	33.7	21.6	17.4	1.47	0.76		77	78
Radiata	47a	23	1127	43.8	21.6	22.3	1.91	0.97			
Blue Range, A.C.T.:											
Muricata	147	23	993	43.4	22.9	21.9	1.89	0.95		71	80
Radiata	147	23	1673	61.1	23.6	27.4	2.66	1.19			
Mt. Burr, S.A.:											
Muricata		17	2076	37.6	15.2	16.8	2.22	0.99		100	86
Radiata		17	2039	37.9	15.5	19.5	2.23	1.15			
Second Valley, S.A.:											
Muricata	209b	19	717	29.8	23.1	20.4	1.57	1.07	17.2	83	81
Radiata	209b	19	801	36.0	23.9	24.4	1.90	1.28	21.1		

MABAI = Mean annual basal area increment
MAHI = Mean annual height increment
MAVI = Mean annual volume increment

In Eire, seed collected from the Muckross Abbey trees was used to establish a series of 0.4 ha plots in conjunction with two Scots pine provenances at five low-altitude sites (J. O'Driscoll, pers. comm.). Heights at 11 years from planting were as follows, with height of Scots pine in parentheses:

Collooney (old woodland): 6.6 m (3.6 m)

Donadea (midland bog): all dead (3.2 m)

Monasterevan A (mineral soil): 3.9 m (3.1 m)

Monasterevan B (midland bog): 3.6 m (2.0 m)

Mullingar (midland bog): all dead (3.2 m)

Rathdrum (mineral soil): 10.6 m (6.9 m)

Survival and growth have been poor on peat bog sites, but excellent on the better sites. Further plantings were made in 1964, 1965, and 1971.

6. *Intrinsic Wood Properties*

Wood properties of four trees of the central green (Δ-3-carene) race of muricata, selected as being of average density, were assessed by Harris *et al.* (1960). Basic wood density averaged 360 kg/m^3 (extracted) for rings one to five and 440 kg/m^3 for the five outermost rings. Weighted tree mean resin contents varied from 0.9% to 4.6% among the four trees and average tracheid lengths varied from 1.5 mm in the first ring from the pith to 4.0 mm at the twelfth and subsequent rings. The values are similar to those for radiata of the same age from Kaingaroa.

Bigwood (1972) studied wood properties of 47-year-old blue muricata from Cpt 1118, Kaingaroa Forest. Basic densities of the outer 10 rings averaged 435 kg/m^3 for 30 trees compared with 490 kg/m^3 for radiata planted the same year in the same compartment. Of these 30 trees Bigwood selected 6 close to the stand mean density and collected 9 discs per tree at 5 m intervals up the stem. Weighted whole tree mean basic density for the six muricata trees averaged 411 kg/m^3, compared with 420 kg/m^3 for radiata sample trees in the same compartment measured 3 years earlier (Harris, 1969). β-ray densitometer data from 1.4 m, 14.6 m, and 34.1 m above ground showed that density rose rapidly over the first five rings from the pith with only a slow rise thereafter. Basic density was also measured independently in five-ring blocks from pith to bark in the first, third, fifth, seventh, and ninth discs. This averaged 387 kg/m^3 for the inner five rings and 435 kg/m^3 for rings 31 to 35 from the pith.

The important difference between the two species lies in the density gradients; radiata shows a steeper pith-to-bark gradient and its corewood values are lower than muricata's, but its outer-wood values are higher. Muricata has a more uniform density. Its lowest values are not as low as those of radiata but its whole tree mean is about the same. For trees grown at wide spacings on short rotations of 25 years, muricata could have a higher whole tree mean density than radiata and will have a higher minimum within-tree density.

D. J. Cown (pers. comm.), using the same β-ray densitometer data from six blue muricata trees in comparison with densitometer data from radiata from a large number of trees, showed that muricata has a rather different pattern of *within-ring* density variation from radiata. The within-ring density *range* in muricata between latewood maximum and earlywood minimum decreases from about 290 kg/m^3 at ring five to 205 kg/m^3 at ring 35 from the pith. Radiata by contrast has a within-ring density range of 190 at ring five to 160 kg/m^3 at ring 35. Latewood maximum density in muricata rises rapidly from the first to the fifth ring from the pith (to about 540 kg/m^3) after which it remains more constant. Earlywood minimum density rises very slightly from pith to bark. Latewood maximum density in radiata is the same as muricata's but earlywood minimum density is much higher, especially in the outer wood. Thus, within-ring density patterns in muricata are somewhat different from those in radiata and greater within-ring variation in density will result in a slightly less even-textured wood. This within-ring density range is nothing like as great as in Douglas fir or southern pines, and the "graininess" is only weakly developed.

Preliminary strength tests of small clear samples of blue muricata (H. R. Orman, pers. comm.) indicate that modulus of rupture and modulus of elasticity are much the same as for radiata when green but increase more on drying. The muricata samples averaged 5% higher than radiata in basic density (420 versus 400 kg/m^3). Modulus of elasticity was 5% higher than in radiata when green and 15% higher when air-dry. Modulus of rupture showed the same pattern; muricata was 1% lower than radiata when green, but 7% higher when air-dry.

7. *Timber Characteristics*

A timber grade study was made on 30 trees of blue muricata from Cpt 1118, Kaingaroa Forest (James and Knowles, 1972). Second logs only (from 5 to 10 m above ground) were sawn almost entirely to 10 × 5 cm scantlings and were graded visually and by machine stress grading. The trees were selected in three classes according to the branching pattern in the part of the bole to be sawn. The uninodal trees which produced one cluster of branches per year all had three clusters of branches in each 5 m log sawn, the binodals averaged 6.7 clusters, and the multinodals had 10.5 clusters.

On average, visual framing grades were highest for the multinodal, intermediate for the binodal, and lowest for the uninodal logs. Where possible the material was also graded as factory grade, in which 50% of the length of a piece must yield defect-free clear cuttings of 0.6 m or longer. The proportion of factory grade was very much higher for the uninodal logs (46%) than for the multinodals (6%), with the binodals intermediate (21%). Likewise, the average size of clear cuttings potentially available from the timber from the uninodals was double that from multinodals. Visual grades were compared with those from a study of old crop second logs of radiata (Fenton, 1967). This comparison indicated that after weighting percentages of grades from the three log types according to their frequency in the stand, muricata would contain slightly higher proportions of No. 1 and No. 2 framing grades, a lower proportion of box grade, and about the same proportion of factory grade. The proportions, with radiata figures in parentheses, were: No. 1 Framing 31 (23), No. 2 Framing 32 (22), Box 15 (32), Factory 22 (23).

When green, the machine stress grades were highest for multinodal, intermediate for binodal, and lowest for the uninodal group, though the absolute differences were small between the groups; mean modulus of elasticity values were 5.16, 4.99, and 4.56×10^3 pascal, respectively. The weighted mean E value for muricata was 4.97×10^3 pascal (after weighting by crop frequencies of uninodal, binodal, and multinodal trees). If the average E values given by Whiteside (1972) for the different visual grades of radiata framing are weighted by the proportions of No. 1 Framing : No. 2 Framing : Box given by Fenton (1967) for the radiata second log study, the estimate for the weighted mean modulus of elasticity for radiata is 4.27×10^3 pascal. With the greater increase in E values on drying shown for the muricata clear samples, it seems probable that muricata timber will be appreciably stiffer and stronger than radiata, at least for timber with the same-sized knots.

Using James and Knowles' raw data, variation in timber stiffness between trees and between log types (uninodal, binodal, and multinodal) was examined. There was far more variation between trees in average modulus of elasticity (mean E) than between the multinodal, binodal, and uninodal groups, and this was related to the variation in average maximum branch diameter and wood density within each group. Overall, for the 30 logs, average branch diameter varied from 2.5 to 5.4 cm and mean wood density of logs (based on discs cut from both ends) varied from 372 to 461 kg/m^3. A multiple regression equation explained 64% of the variance ($R^2 = 0.64$) in log average modulus of elasticity by variation in knot diameter and wood density. Simple correlations between mean E and knot diameter, wood density, and branch cluster number were calculated as: -0.77, 0.22, and 0.28, respectively.

The number of branch clusters in the log, however, was the key factor in determining the percentage of factory grade and mean lengths of clear cuttings. Some trees gave aberrant results because a large proportion of their timber was downgraded by needle flecks, which resemble pin knots, and are caused by persistent needles on the stem. It is not known how common needle fleck is in this species.

Sawn material from this timber grading study was used by Kininmonth and Williams (1972) to study the kiln drying characteristics of muricata timber. Paired samples of twelve 10×5 cm scantlings of muricata and radiata as well as ten 15×2.5 cm boards (from top logs sawn to 2.5 cm timber for this purpose) of both species were kiln dried together, using commercially-recommended schedules for radiata. Shrinkage in width and thickness was similar for the two species. Drying rates for muricata were slightly (5-10%) lower than those for radiata. Distortion in muricata was not excessive; no boards would be rejected for bow (on Australian grading rules for building grade) and only 3.9% for twist. These rates were similar to those for radiata.

During the collection of detailed branch and stem cone data on these trees (Shelbourne, unpublished data) it was observed that onset of stem coning apparently occurs at about the same height on the stem as in radiata; the average height of first stem cone for the 30 trees in the sawing study was 12.5 m, versus 10.5 m in a study by Bannister (1962) on radiata. Moderate or heavy stem coning did not start until an average height of 16.0 m in the muricata sample. The stem cone holes, like the cones themselves, were much smaller than in radiata and were found to occlude 10 to 15 cm from the pith.

8. *Extractives Content*

In a study of resin content (methanol solubles) of blue muricata and green muricata from Cpt 1217 and radiata from Cpt 1211, Kaingaroa, Lloyd (1973) sampled 30 trees in each muricata provenance and 10 trees of radiata by increment cores at breast height. Results were as follows:

	Resin content (%)	
	Heartwood	*Sapwood*
Muricata (blue)	10.2 S.D. 3.7	2.2 S.D. 0.3
Muricata (green)	8.7 S.D. 4.3	2.5 S.D. 0.4
Radiata	5.8 S.D. 2.1	1.8 S.D. 0.5

While the heartwood of blue muricata contained nearly double the amount of resin found in radiata heartwood, the sapwood contained only 2.2% compared with 1.8% in radiata. Heartwood percentage of blue muricata in Cpt 1118 (determined by Bigwood) averaged 38% for six trees and 28% for radiata from the same compartment.

The amount of heartwood and thus the whole-tree average resin content should be much lower in trees grown on shorter rotations, where the sapwood resin content will have the most effect.

9. *Pulping and Papermaking Properties*

The papermaking properties of mechanical and kraft pulps of muricata were investigated by Uprichard *et al.* (1972). Pulpwood samples were obtained from the 15th and 25th internode from the apex of five trees from the same stand sampled by Bigwood. Refiner groundwood pulps prepared in the laboratory gave strength properties similar to those prepared for radiata. Kraft pulps gave good strength properties and possibly better retention of tear factor on beating than radiata pulps. The uniformity of density from pith to bark found by

Bigwood was confirmed; the average range of basic density between the inner five rings and the outer five rings in the 25th internode sample was 392 to 424-kg/m^3. Methanol extractives or resin content in the two parts of the tree sampled averaged about 2% except in the inner five rings where it averaged about 7.5%. This agrees fairly well with Lloyd's findings. The authors conclude that the pulping properties of muricata are generally good and similar to those of radiata.

RESULTS OF GROWTH STUDIES IN NEW ZEALAND

A number of separate studies comparing the growth of muricata with that of radiata have been made by various workers. These will be reported separately because the methods used, the variables measured, and the age of the stands assessed differ widely.

1. *Comparative study of growth rate and stem and branch morphology of radiata and blue muricata*

In the first study neighbouring stands of blue muricata and radiata of similar age were found at Cpts 1118 and 1119 Kaingaroa, Cpt 7 Kaingaroa, and Cpts 31 and 32 Golden Downs (see Fig. 2 for locations of these and other stands). Together these three stands occupy over half the total area of mature blue muricata in New Zealand. Cpts 1118 and 1119 Kaingaroa were planted in 1925 on a rolling site in the northern part of the forest at an altitude of 550 m. At Cpt 7 Kaingaroa, altitude 400 m, the stands studied were natural regeneration from stands planted in the early 1900s and felled in 1946 and 1947. At Golden Downs the stands were planted in 1936 and 1937 at an altitude of about 400 m. All three sites would be rated as good environments for radiata.

Thirty-six tree-variable radius plots (Prodan, 1968) were randomly located in each stand. The closest six trees to the sampling point were measured for diameter at breast height and assessed for bole straightness (subjective rating 1 to 9), presence or absence of forks, a visual estimate of average maximum branch diameter per cluster, and branching pattern (uninodal, binodal, or multinodal). The heights of two randomly chosen trees were measured in each plot.

The results of these measurements are shown in Table 4. Muricata is 9% shorter than radiata in Cpts 1118 and 1119 Kaingaroa, 17% shorter in Cpt 7 Kaingaroa, and 23% shorter at Golden Downs. The radiata at Golden Downs and both species in Cpt 7 Kaingaroa had been thinned and stockings were higher in the muricata. This resulted in smaller diameters and larger basal areas in the muricata stands. The old crop stands of both species at Kaingaroa (Cpts 1118, 1119) had not been thinned. The higher stocking of muricata was a consequence of fewer muricata stems being killed in the *Sirex* wood wasp outbreak in the 1950s. The basal area in this stand, however, exceeds that in the nearby radiata stand (and most other Kaingaroa radiata stands). The muricata in each case had greater total standing volume than the radiata.

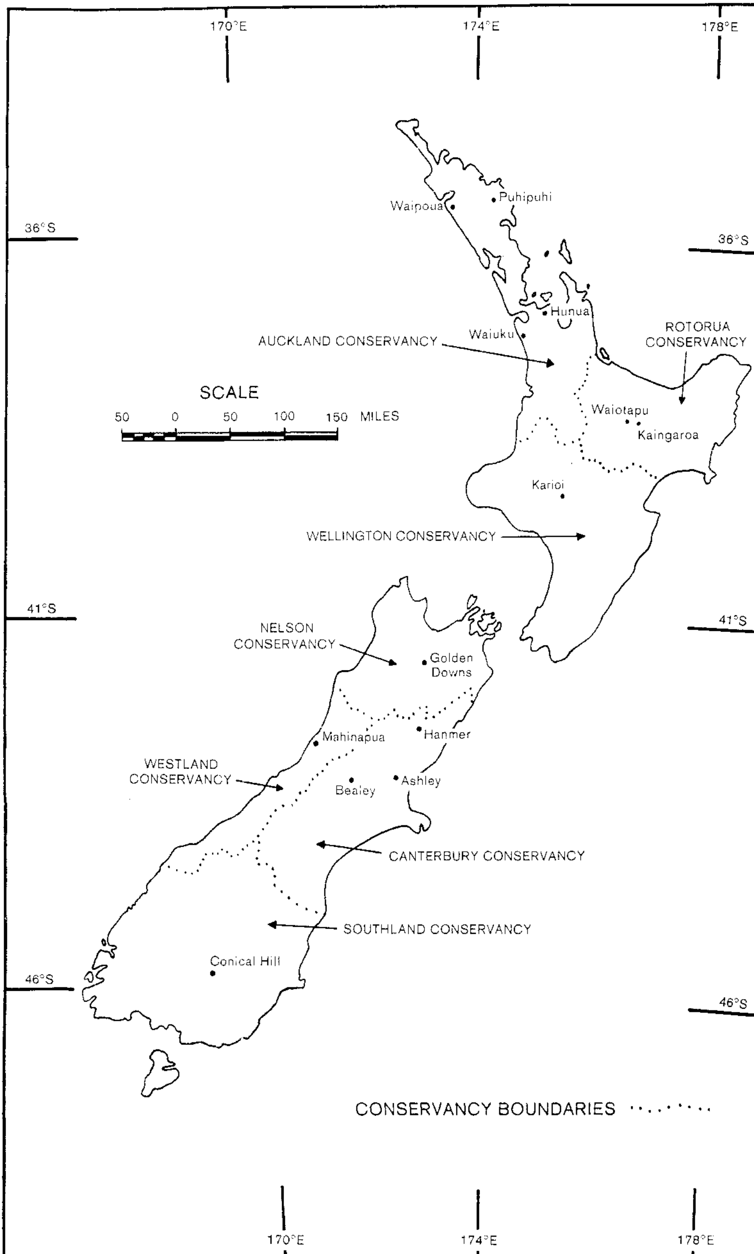


FIG. 2: *Forests with blue muricata plantings.*

Bole straightness of muricata was consistently superior to that of radiata and percentage of forked stems was about the same. Branch diameters cannot be easily compared because of the differences in early stocking, but the indications are that muricata would, on average, develop somewhat larger branches than radiata at the same stocking. This may be due to the higher frequency of uninodal and binodal tree types in the muricata. In muricata stands, 1 in 100 stems is straight and perfectly uninodal, whereas to select a similar tree in radiata it is necessary to screen about 5000 trees.

2. *Height-age relationship in Cpt 1118, Kaingaroa*

Forty trees in Cpt 1118, Kaingaroa Forest, were studied in order to reconstruct the course of height growth. The average height-on-age curve for 40 trees in this stand is shown in Fig. 3. Superimposed in the same figure are the curves for

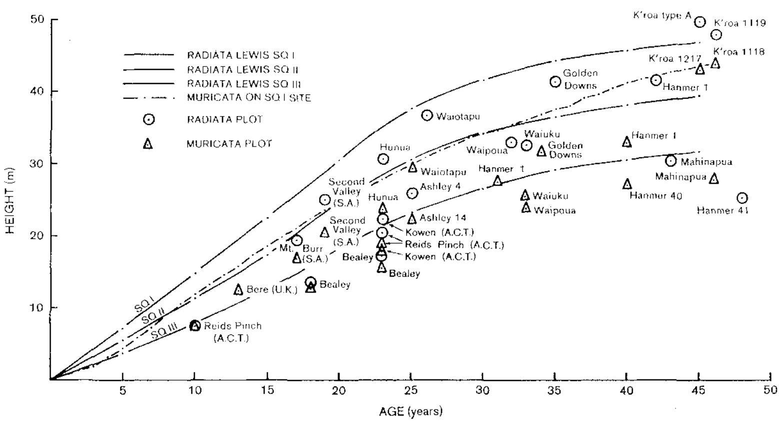


FIG. 3: *Height curves for muricata and radiata.*

radiata published by Lewis (1954). The height of radiata in neighbouring Cpt 1119 falls almost exactly on the Quality 1 curve, which is site index 100 or a height of 30.5 m (100 ft) at 20 years. The muricata averaged 24.6 m at 20 years. Between age 30 and 45 years, however, the rate of height growth of muricata remains constant without the characteristic decrease found with radiata.

3. *Mensurational assessment of Kaingaroa muricata*

In a recent assessment of all stands of green and blue muricata in Kaingaroa, C. J. Mountfort (pers. comm.) made an extensive survey of 836 ha of the green provenance and carried out an intensive comparison of blue and green provenances in Cpt 1217, with fifteen 0.08 ha plots of each. The only other large stand of blue muricata in Kaingaroa, Cpt 1118, was sampled similarly (Table 5).

TABLE 4: COMPARATIVE STUDY OF GROWTH AND MORPHOLOGY OF MURICATA AND RADIATA BASED ON 30 SIX-TREE VARIABLE RADIUS PLOTS PER STAND

Forest and Species	*Cpt*	*Age*	*Stocking (stems/ha)*	*Basal area (m^2/ha)*	*dbh (cm)*	*Height (m)*	*Total Standing volume (m^3/ha)*	*MABAI*	*MAHI*	*MAVI*	*Straightness (1-9)*	*Forks (%)*	*Branch diam. (cm)*	*Multinodal (%)*	*Binodal (%)*	*Uninodal (%)*
Golden Downs:																
Muricata	31	34	917	83.1	33.3	31.4	878	2.44	0.92	25.8	5.9	29	6.6	19	47	33
Radiata	32	35	269	54.9	50.0	41.1	705	1.57	1.18	20.2	5.4	28	10.4	56	30	14
Kaingaroa:																
Muricata	7	25	655	57.2	32.8	29.3	585	2.29	1.17	23.4	6.4	8	6.9	40	39	21
Radiata	7	26	447	53.7	38.1	36.9	689	2.07	1.42	26.4	4.4	16	7.1	61	29	9
Kaingaroa:																
Muricata	1118	46	371	99.2	57.4	43.9	1386	2.16	0.95	30.2	5.9	23	12.4	32	50	18
Radiata	1119	46	272	87.0	62.5	47.9	1306	1.89	1.04	28.4	5.1	19	11.2	62	27	11

MABAI = Mean annual basal area increment
MAHI = Mean annual height increment
MAVI = Mean annual volume increment

TABLE 5: MENSURATIONAL ASSESSMENT OF KAINGAROA MURICATA STANDS

Provenance	*Cpt*	*Age*	*Normal stems/ha*	*Malformed stems/ha*	*Total stems/ha*	*Normal BA/ha (m^2/ha)*	*Malformed BA/ha (m^2/ha)*	*Total BA/ha (m^2/ha)*	*Mean dbh (cm)*	*Height (m)*	*Total standing volume (m^3/ha)*
Blue	1217	45	205	35	240	57.9	8.0	65.9	59.2	43.0	948
Green	1217	45	171	72	245	36.3	16.5	52.8	52.3	34.4	613
Blue	1118	46	257	77	336	67.5	22.7	89.8	58.4	43.0	1297
Green	All	42-45	371	153	524	61.5	25.0	86.5	45.7	33.2	988

The total standing volume in similarly stocked stands of blue and green provenances on adjacent sites in Cpt 1217 is 55% greater in the blue. There are twice the number and basal area of malformed trees in the green provenance than in the blue. Volume superiority of the blue is due to a higher basal area and much better height growth. These stands, which are located at an altitude of 210 m close to the Galatea plains, were attacked more heavily by *Sirex* than were other parts of the forest and the sites are still not completely re-occupied. The average stocking of the green muricata stands over the whole forest was 524 stems/ha compared with 245 stems/ha in Cpt 1217. Similarly, in the blue muricata of Cpt 1217 the stocking was 240 stems/ha compared with 336 stems/ha in Cpt 1118 (altitude 550 m). While basal area was 65.9 m^2/ha in Cpt 1217 and 89.8 m^2/ha in Cpt 1118, mean diameters in both blue stands were about 58 cm, indicating that in Cpt 1217 the site is not fully occupied. The discrepancy between volumes, basal areas, and stocking estimated from this study and the FRI study can be ascribed to an upward bias for stocking caused by the variable-radius plot technique (J. Beekhuis, pers. comm.).

4. *Paired-plot comparisons of muricata and radiata at Waiuku and Waipoua*

A stand of blue muricata planted in 1939 at Waiuku Forest on a coastal sand dune was compared with a neighbouring stand of radiata (J. D. Hayward, pers. comm.). Fifteen plots were located near the adjacent stand margins of each species. An angle gauge was used to determine basal area at each point and the two tallest trees within 30 m of each plot centre were measured for height and diameter.

The mean basal area per hectare, average heights of the measured dominants, and their diameter are shown in Table 6 (lines 1 and 2). In this table mean annual increments for basal area, height, and total volume (MABAI, MAHI, and MAVI) have been calculated for each species, and the ratio of these values for muricata:radiata have been calculated for each comparison. On this site the basal area ratio is 94 and height ratio is 78, indicating that growth rate of muricata on this low-altitude sand-dune site is well below that of radiata. Heights of these stands and others discussed below are also shown on Fig. 3.

Stands of muricata and radiata were compared on phosphate-deficient soils at Waipoua by means of fifteen 0.02 ha plots near the adjacent stand margins in each species (J. D. Eyre, pers. comm.). Although the muricata was of mixed green and blue provenances with some hybrids, most of the two dominant trees per plot measured for height were blue.

The height ratio of muricata to radiata was 70, basal area was 118, and volume was 90. Stocking in the unthinned muricata stand was, however, much higher than in the thinned radiata. The growth rate of muricata was inferior to radiata on this warm Northland site, though the presence of trees of green provenance and hybrids between blue and green make any firm conclusions impossible.

TABLE 6: SUMMARY OF MURICATA SAMPLE PLOT DATA WITH RADIATA COMPARISON

Forest and Species	*Cpt*	*Age*	*Stocking (stems/ha)*	*Basal area (m^2/ha)*	*dbh (cm)*	*Height (m)*	*Total standing volume (m^3/ha)*	*MABAI*	*MAHI*	*MAVI*	*M:R MABAI*	*M:R MAHI*	*M:R MAVI*
Waiuku:													
Muricata	16	33		33.3	38.9	25.2		1.01	0.76		94	78	
Radiata	8, 17	33		35.4	45.2	32.4		1.07	0.98				
Waipoua:													
Muricata	7-7	33	717	55.3	31.2	23.8	447	1.68	0.72	13.5	118	70	90
Radiata	4-6	32	272	45.5	46.2	32.9	481	1.42	1.03	15.0			
Puhipuhi:													
Muricata	Shelterbelts	67				28.0			0.42			91	
Radiata		67				31.1			0.46				
Hunua:													
Muricata		23	346	50.7	43.2	23.6	392	2.21	1.03	17.0	96	77	76
Radiata		23	371	52.6	42.4	30.5	518	2.29	1.33	22.5			
Kaingaroa:													
Muricata*	1118	46	371	99.2	57.4	43.7	1386	2.15	0.95	30.2	114	91	106
Radiata	1119	46	272	87.0	62.5	47.8	1306	1.89	1.04	28.4			
Muricata†	1118	46	336	89.8	58.4	43.0	1297	1.95	0.94	28.2	120	83	111
Radiata Nthn Type 'A'		43.9	259	71.4	59.2	49.7	1117	1.63	1.13	25.5			
Muricata†	1217	45	240	65.9	59.2	43.0	948	1.47	0.95	21.1	90	84	83
Radiata Nthn Type 'A'		43.9	259	71.4	59.2	49.7	1117	1.63	1.13	25.5			
Muricata*	7	25	655	57.2	32.8	29.3	585	2.29	1.17	23.4	111	83	88
Radiata	7	26	447	53.7	38.1	36.7	689	2.07	1.41	26.5			

Golden Downs:													
Muricata*	31	34	917	83.1	33.3	31.4	878	2.45	0.92	25.8	156	78	128
Radiata	32	35	269	54.9	50.0	41.2	705	1.57	1.18	20.2			
Muricata	31	34	1166	105.4	34.0	34.4	1209	3.10	1.01	35.5	121	96	112
Radiata	22	39	944	100.6	36.8	40.8	1236	2.57	1.05	31.7			
Ashley:													
Muricata	14	25	247	29.4	38.6	22.3	227	1.18	0.89	9.1	54	90	47
Muricata	4	24	272	22.3	32.3	23.8	176	0.93	0.99	7.3			
Radiata	4	25	605	48.7	32.3	25.9	436	1.95	1.04	17.4			
Hanmer:													
Muricata	1	31	272	49.4	48.0	27.4	460	1.59	0.88	14.8	108	86	72
Muricata/	1	40	111	23.7	52.1	32.9	265		0.82				
Douglas fir‡		40	766	71.2	28.7	30.5	487		0.76				
Radiata	1	42	445	62.0	42.2	41.5	865	1.48	0.99	20.6			
Muricata	8	63			81.5	40.8			0.65			107	
Radiata	4	64	274	98.9	67.8	39.0	1088		0.61				
Muricata	40	40	455	63.6	42.2	26.7	460	1.59	0.67	11.5	111	129	102
Radiata	41	48	850	68.6	32.0	25.0	541	1.43	0.52	11.3			
Mahinapua:													
Muricata	10	46	741	105.8	41.4	27.7	1189	2.30	0.60	25.8	170	86	194
Radiata	8	43	289	58.1	49.5	30.2	573	1.35	0.70	13.3			
Conical Hill:						33.5			0.58			89	
Muricata	6	58											
Radiata	6	61				39.6			0.65				
Means											117	89	106

*FRI 6-tree variable radius plot study
†C. J. Mountfort (pers. comm.)
‡Mixed

5. *Local forest sample plots*

Almost every stand of blue muricata in New Zealand, apart from young stands of regeneration less than 10 years old, has been compared with a neighbouring radiata stand. The total area of these older stands is small (106 ha) and distribution is restricted; for instance, they include only one shelterbelt planting south of Christchurch. In Kaingaroa Forest and at Golden Downs, intensive and reasonably precise stand comparisons were made involving large numbers of sample plots. In most other forests, only one to three sample plots of 0.2 to 0.1 ha in area have been used to characterize each stand (15 plots in each at Waiuku and Waipoua), and consequently these individual estimates are subject to large errors.

These mensurational data are shown in Table 6, and those for height on age in Fig. 3. Height growth is usually accepted as the most convenient index of growth rate within a species, but it has serious limitations when comparing the growth of different species; a species may be shorter, yet be capable of greater wood production/hectare than another. However, height is the only growth index that is almost independent of stocking. On most sites the ratio of mean annual height increment of blue muricata to radatia is less than 100, exceeding this figure only twice in Table 7 — at Hanmer at altitude 390 m in 63-year-old stands, and in stands at Hanmer at 630 m where it is 128. These last two stands are the only mature stands of muricata and radiata that are growing above the local altitudinal limits of radiata. There is a tendency with advanced age for the height ratio to approach 100 (*e.g.*, at Puhipuhi (age 67), at Kaingaroa Cpt 1118 (age 46), and at Hanmer Cpt 8 (age 63). On sites except those at higher altitudes, the height of muricata averages 85% that of radiata.

TABLE 7: HIGH-ALTITUDE SPECIES TRIAL AT MT GREY, ASHLEY
(Measurements after 6 years)

	(%) *Survival*		(*m*) *Height*		(%) *Malformation*	
Species Altitude (*m*):	*690*	*910*	*690*	*910*	*690*	*910*
Picea sitchensis	100	97	0.79	0.91	25	20
Pinus contorta	96	94	2.35	2.07	66	64
Pinus jeffreyi	77	78	0.79	0.82	44	57
Pinus monticola	30	5	1.28	1.07	31	44
Pinus muricata	82	59	2.62	1.83	28	51
Pinus nigra (1)	98	97	1.74	1.40	12	22
Pinus nigra (2)	90	86	1.59	1.40	12	26
Pinus ponderosa (3)	93	91	1.16	1.19	62	65
Pinus ponderosa (4)	33	62	1.46	1.22	59	67
Pinus radiata	44	49	2.10	1.55	67	55
Pseudotsuga menziesii	93	95	1.52	1.28	53	58

(1) and (2) Seedlot Nos. C64/495 and C64/497, respectively.
(3) and (4) Seedlot Nos. S63/757 and FRI 64/1714, respectively.

Basal area/ha for muricata was found frequently to exceed that of radiata, but this was often attributable to radiata stands having been thinned, unlike those of muricata. However, there were some indications that muricata can tolerate denser stockings and still have larger basal areas than radiata (*e.g.*, Kaingaroa Cpt 1118, Golden Downs Cpt 31), a factor which would be an advantage for pulpwood regimes. Basal areas and total standing volumes of muricata averaged respectively 117% and 106% of radiata's. In the few instances where stocking and treatment had been the same — *i.e.*, Cpt 1217 Kaingaroa and at Hunua (A. J. Dakin, pers. comm.) — both species had the same diameter at breast height.

Hence it could be hypothesized that on normal radiata sites, under modern silvicultural regimes, muricata and radiata will take the same time to reach a given diameter at breast height. As muricata will be shorter, however, volume will be less. On progressively higher-altitude sites, radiata would lose its height advantage, and total and merchantable volumes of muricata are likely to exceed radiata's before that happens.

At Mahinapua in Westland, on nutrient-deficient, poorly-drained soils, in a mild wet climate, muricata appears to be better adapted and more productive than radiata though its height is still only 85% of radiata's. No comparisons are available from Southland apart from the heights in the 58-year-old shelterbelt at Conical Hill, but in this region muricata could be expected to perform better relative to radiata than further north.

6. *Conservancy species and establishment trials*

High-altitude species trials have not been generally established throughout New Zealand and few contain blue muricata. Canterbury Conservancy staff, however, established a trial with nine species including blue muricata in 1967. The trial involved three replications of 40 trees each, at 0.6 m spacing at altitudes of 690 m and 910 m on Mount Grey, Ashley Forest. Results from measurements at age 6 years are given in Table 7 (P. G. Waldron, pers. comm.).

Survival of muricata and radiata was reduced because the planting stock was stored under snow for too long. It is evident, however, that the height growth of muricata is superior to all other species at the 690 m site, while at the 910 m site contorta is taller than the muricata. Height ratios of muricata to radiata were 123 and 117, respectively, at these sites. Malformation for muricata and contorta was caused primarily by opossums, but in radiata it was caused by climatic damage. Muricata was the least malformed of these species.

A species trial was established at Burnt Face, Bealey Forest, in 1947. The site is at 700 m on a steep hillside in which the row plots run across the contour. Measurements at age 23 (D. G. K. Viles, pers. comm.) showed that Douglas fir is apparently outgrowing radiata and muricata in height (see Table 8), though these means are based on only three or four trees per species. Competition effects between row plots are

TABLE 8: SPECIES TRIAL AT BEALEY FOREST
(altitude 700 m)

Species	*Age 23* Height (m)	dbh (cm)
Radiata pine	17.4	37.8
Muricata pine (green and blue)	15.5	33.0
Corsican pine	9.8	20.3
Contorta pine	9.1	21.6
Ponderosa pine	7.3	25.1
Douglas fir	18.3	34.0

also causing the slower-grown plots to become suppressed. The results of resin analysis of five trees of muricata indicated that three of these were of green provenance or were hybrid blue × green. Thus, these results are not a reliable indication of blue muricata's performance.

Species trials were planted at Karioi at various altitudes up to 1220 m in 1929. The trial in Cpt 52 at altitude 975 m contained green muricata and radiata as well as several other species. Results of an assessment of the muricata and radiata at age 42 years are shown in Table 9.

TABLE 9: KARIOI SPECIES TRIAL (CPT 52, AGE 42 YEARS, ALTITUDE 975 m)

Species	*Survival (%)*	*Height (m)*	*dbh (cm)*	*Forks (%)*	*Straightness (1-9)*
Muricata (green)	77	21.6	51.4	75*	6.05
Radiata	32	31.4	65.4	100	4.44

*Only 35% forked above 2 m

In spite of its considerable growth, radiata on this site had suffered such serious malformation and high mortality that it would not be worth while to harvest the timber. The green muricata was much straighter and suffered much less malformation above 1.8 m, though many trees were forked below this level. Data from Kaingaroa showed that height of green muricata is 75% that of the blue, which indicates that blue muricata would probably have equalled radiata in height growth on the Karioi site but would have shown much better form.

Two experiments were established in 1965 and 1967 in Westland to compare the growth of muricata, radiata, and contorta pines, and sitka spruce. In the Wallaroo intermediate-terrace establishment trial at Mawhera Forest, height of muricata averaged 68% of radiata's at age 3 (R. W. Washbourn, pers. comm.). On the high-terrace drainage and fertilizer trial at Paporoa, muricata averged 75% of radiata's height growth in the 1965 experiment in spite of very heavy attack by opossums in the first 2 years, and 72% in the 1967 plantings (R. J. Jackson, pers. comm.). These height ratios are fairly typical of muricata and radiata juvenile growth rates on warm sites. Subjective observations of health of the two species have indicated that muricata is superior under these conditons and results from the mature sample plots in Mahinapua Forest tend to confirm this.

The significance of opossum damage on muricata is uncertain. Although no comparative data are available, muricata is reputed to be much more susceptible to damage by opossums than radiata is, but less so than contorta. Unfortunately, stands of blue muricata of varying ages are not available in areas with high opossum populations. It is not known how much damage will occur under normal forest management.

Older stands of blue muricata are lacking on the higher-altitude flat sites in southern Kaingaroa. Severe winter and summer frosts can cause repeated frost damage and mortality in radiata on these sites. An experiment was established by forest staff in 1970 in Cpt 489, situated at altitude 600 m and previously carrying ponderosa pine. The aim was to investigate the effects of different land preparation techniques and planting times with radiata. Some comparative plantings of blue muricata were also included.

Muricata and radiata planted in September 1970 were assessed in May 1973, and 60 trees were measured for height in each species in four different site preparation types. Bud damage was scored on a scale of 1 (no damage) to 5 (most buds killed), and survival was based on all trees in the September planting.

Height averaged 109 cm for radiata and 106 cm for muricata; corresponding figures for bud death were 2.15 and 2.23, with 67 and 85% for survival.

The species comparisons are confounded by nursery stock differences because the muricata was healthy 1-year-old stock from Owhata Nursery, while the 2-year-old radiata stock from Kaingaroa Nursery had suffered excessive copper spraying which adversely affected survival and early growth. It appears, however, that growth of the two species on this site is much the same after making allowances for age and condition of stock.

Further comparisons of juvenile height growth were made at Cpt 864 Kaingaroa, altitude 680 m, located on a similar flat site to Cpt 489 and with slightly better air drainage. Radiata and muricata had been machine-planted as 2/0 stock. The muricata, topped in the summer before planting, was from Owhata Nursery, while the radiata came from Kaingaroa Nursery. At 2 years from planting, over 95% of each species (in adjacent rows) were surviving and mean heights were 81 cm for muricata and 83 cm for radiata. No bud damage was apparent, though old crop radiata growing about 100 m away showed very frequent and repeated malformation.

Cpt 1350 Kaingaroa Forest, altitude 410 m in northern Kaingaroa, is a much warmer and undulating site. At 2 years from planting, 1/0 stock of radiata from FRI Nursery (particularly small at time of planting) was 118 cm tall, while 2/0 topped stock of muricata from Owata Nursery was only 101 cm.

It can tentatively be concluded from these early growth comparisons in Kaingaroa Forest that on the high-altitude coldest sites muricata is growing as fast as radiata, and on the warm sites at lower altitude radiata is growing faster than muricata.

DISCUSSION AND CONCLUSIONS

The height growth of blue muricata averages about 85% of that of radiata on sites where radiata has proved completely successful. Apart from very recent plantings only three stands in New Zealand have been found where blue muricata is growing at altitudes over 610 m. These were at 620 m at Hanmer, and in the two young species trials on Mt Grey (Ashley) at 690 m and 910 m, where height growth figures for muricata are, respectively, 128, 123, and 117% of those for radiata. From this limited information, it could be expected that above a certain altitude (which will depend on latitude and other local climatic and soil factors) height growth of muricata will exceed that of radiata. This altitude can only be guessed at but would probably be between 460 and 600 m in the South Island and between 600 and 800 m in the central North Island.

Height growth, however, is of limited use in growth comparisons between species. In low-altitude environments, radiata is an appreciably taller tree than blue muricata though under the same stocking on these sites the two species appear to reach the same mean diameter and basal area. Total volume of muricata will be less than that of radiata but until more accurate volume tables are available the extent of this difference will not be known.

Ambient temperature and extreme low temperatures are partly governed by altitude; lower ambient temperatures result in slower growth rates, and extreme frosts, especially unseasonal frosts, can result in poor survival and malformation. It appears that muricata tolerates these conditions better than radiata. High-altitude sites are also more subject to snowfalls and these are some indications (from Hanmer and Karioi) that muricata suffers less snow breakage and subsequent malformation than radiata.

There are indications from Westland that muricata tolerates infertile and poorly-drained soils better than radiata does and shows superior health and volume production under these conditions. However, muricata is inferior to radiata in growth on coastal sand dunes and phosphate-deficient gumland clay soils in Northland although warmer climates may have been the decisive factor in these cases.

Muricata has not been compared with contorta as it soon became evident in this study that the problematic comparison of productivity was with radiata. Contorta can be expected to be much less productive than either radiata or muricata and should be planted only when all else fails. Evidence from conservancy sample plots, at Golden Downs, Karioi, and Beaumont indicates that contorta carries two-thirds to three-quarters of the standing volume of green muricata and about half the standing volume of blue muricata.

There is some evidence that opossum attack and damage muricata more than they do radiata, although contorta, the only alternative species for harsh sites, is undoubtedly damaged even more severely. Little experience on the incidence of opossum damage is available, however, on compartment-sized plantings of muricata. Opossum control measures will have to be intensified in areas planted with either contorta or muricata.

From the utilization standpoint, muricata has wood properties and branch and stem morphology which will not prevent it from being marketed with radiata and which offer certain advantages. The relative uniformity of wood density from pith to bark and the absence of a very low density core, combined with a whole tree density the same as that of radiata, are an advantage for sawing and pulping. The corewood will be of generally better quality in muricata and higher working stresses should be permissible. On short rotations whole tree density of muricata should be higher. Superior dry timber values for modulus of elasticity and modulus of rupture are also important advantages.

The higher frequency of uninodal and binodal branching in muricata may result in a tendency to produce larger knots but this also results in higher yields of clear cuttings for remanufacture. The selection of straight, perfectly uninodal trees is much easier in muricata and a uninodal strain could probably be produced more easily with this species than with radiata. Contrary to some opinions, onset of stem coning was found no earlier in life or lower on the stem in blue muricata than in radiata and the stem cone holes which are smaller eventually occlude.

In New Zealand, there is, as yet, only a limited need to afforest high-altitude land for production purposes, as much land is available for forestry at lower altitudes. However, production forestry is beginning to move into the large areas of land over 450 m altitude in Southland and Canterbury, and in the North Island the higher parts of Karioi, Kaweka, Ruatoria, and Kaingaroa forests are probably better suited to blue muricata than radiata. If the preliminary indications that muricata has superior frost tolerance to radiata are substantiated, muricata would be preferred to the less productive contorta on localized frost-prone sites. As few of these frost-prone or high-altitude sites have been planted with blue muricata in the past, trial plantings must now be made on a wide scale to provide knowledge for future planning. In addition, with the possibility of extensive conversion of beech/podocarp forest in Westland to exotics, the possible superiority of muricata to radiata on wet, poorly-drained soils should be tested.

Further information is therefore required on several aspects of this species, including:

(1) Comparison with radiata of behaviour and yields on short-rotation sawlog silvicultural regimes, and also pulpwood regimes, on a wide variety of sites, particularly poor-quality ones.

(2) Comparison with radiata of *Dothistroma* resistance on various sites.

(3) Comparison with radiata of susceptibility to leader die-back on sites where die-back is serious.

(4) Comparisons with radiata of cold and frost tolerance in growth chamber studies.

(5) Comparison of the time-course of heartwood development with radiata.

(6) Follow-up studies of suitability for mechanical pulping.

(7) Follow-up studies on intrinsic wood properties, including strength properties of small clears, and also incidence of needle fleck.

In cool maritime and Mediterranean-type climates in other parts of the world this species has very rarely been tried. Growth rates in Britain, at Bedgbury and Bere, are extremely high for poor soils at a latitude of 51° N, exceeding those for sitka spruce. Indigenous pine species in the Mediterranean region are not very productive and muricata had not been introduced there until very recently. Bearing in mind the importance of radiata in warm temperature, subtropical, and Mediterranean regions, it is interesting to speculate as to what place its little-known and cold-hardier relation will have in the future.

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REFERENCES

Bannister, M. H., 1962: Some variations in the growth pattern of *Pinus radiata* in New Zealand. *N.Z. Jl Sci.*, 5 (3): 342-70.

——— 1966: Notes on *Pinus muricata* and *Pinus attenuata*. *In* The role of pine species other than radiata pine in New Zealand forestry. *Documents produced for For. Res. Inst. Symp. 7.* Compiled by G. C. Weston (unpubl.).

——— 1972: Variation and relationships of *Pinus muricata. N.Z. For. Serv., For. Res. Inst., Genet. and Tree Impr. Work Plan 99* (unpubl.).

Bigwood, S. R., 1972: The wood properties of *Pinus muricata* ("blue strain) from Compartment 1118 Kaingaroa Forest. *N.Z. For. Serv., For. Res. Inst., For. Prod. Lab. Rep. WQ20* (unpubl.).

Burdon, R. D.; Bannister, M. H., 1973: Provenances of *Pinus radiata*: their early performance and silvicultural potential. *N.Z. Jl For. 18* (2): 217-32.

Cobb, F. W.; Libby, W. J., 1968: Susceptibility of Monterery, Guadalupe Island, Cedros Island and Bishop pines to *Scirrhia* (*Dothistroma pini*), the cause of red band needle blight. *Phytopathology, 58* (1): 88-90.

Duffield, J. W., 1951: *Interrelationships of the Californian Closed-cone Pines with Special Reference to* Pinus muricata *D.Don.* Ph.D. thesis, University of California, Berkeley.

Fenton, R. T., 1967: A timber grade study of first rotation *Pinus radiata* D.Don from Kaingaroa Forest. *N.Z. For. Serv., For. Res. Inst., Tech. Pap. 54.*

Fielding, J. M., 1961: Provenances of Monterey and Bishop pines. *Aust. For. Timb. Bur., Canb. Bull. 38.*

Forde, M. B.; Blight, N. M., 1964: Geographical variation in the turpentine of Bishop pine. *N.Z. Jl Bot.,* 2 (1): 44-52.

Harris, J. M., 1969: Wood properties of *Pinus radiata* used in groundwood trials in 1969. *N.Z. For. Serv., For. Res. Inst., For Prod. Br. Rep. 286* (unpubl.).

Harris, J. M.; Orman, H. R.; Kripas, S., 1960: The wood properties of *Pinus muricata* D.Don grown in Kaingaroa State Forest. *N.Z. For. Serv., For. Res. Inst., For. Prod. Br. Rep. 52* (unpubl.).

James, R. N.; Knowles, R. L., 1972: A timber grade study of "old crop" *Pinus muricata. N.Z. For. Serv., For. Res. Inst., Econ. Silvi. Rep. 62* (unpubl.).

Kininmonth, J. A.; Williams, D. H., 1972: The kiln drying of *Pinus muricata* sawn timber. *N.Z. For. Serv., For. Res. Inst., For Prod. Lab. Rep. No. TD16* (unpubl.).

Lewis, E. R., 1954: Yield of unthinned *Pinus radiata* in New Zealand. *N.Z. For. Serv., For. Res. Inst., For. Rep. Notes 1 (10).*

Libby, W. J., 1971: The third-year California data from the Californian coastal closed-cone pine common-garden experiment (unpubl. MS).

Lindsay, A. D., 1932: Bishop pine (*Pinus muricata* D.Don) in its native habitat. *Aust. Commonw. For. Bur., Canb. Bull. 11.*

Lloyd, J., 1973: Extractives of *Pinus muricata* wood. *N.Z. For. Serv., For. Res. Inst., For. Prod. Div. Rep. 455* (unpubl.).

Long, A. J., 1971: *Relative Resistance to Red Band Needle Blight* (Dothistroma pini *Hulbary*) *in the California Coastal Closed-cone Pines.* M.S. thesis, Univ. Calif., Berkeley.

Mirov, N. T., 1947: Composition of gum turpentine of Bishop pine. *J. For., 45*: 659-60.

Mirvo, N. T.; Zavarin, E.; Snajberk, K.; Costello, K., 1966: Further studies of turpentine composition of *Pinus muricata* in relation to its taxonomy. *Phytochemistry, 5*: 343-55.

Parker, A. K.; Collis, D. G., 1966: Dothistroma needle blight of pines in British Columbia. *For. Chron., 42* (2): 160-1.

Poynton, R. J., 1972: Tree planting in southern Africa (unpubl. MS).

Prodan, M., 1968: (Point Sampling for management surveys). *Forst-u Holzwesen, 23* (11): 225.

Shelbourne, C. J. A., 1971: Genetic variation studies in *Pinus muricata. N.Z. For. Serv., For. Res. Inst., Genet. and Tree Impr. Work Plan 114* (unpubl.).

———— 1973: *Pinus muricata* provenance variation in height and state of flushing of the terminal bud, 12 months from sowing. *N.Z. For. Serv., For. Res. Inst., Genet. and Tree Impr. Int. Rep. 40* (unpubl.).

Shelbourne, C. J. A.; Zabkiewicz, J. A.; Allan, P. A., 1973: Monoterpene composition in provenances of *Pinus muricata* planted in New Zealand. *N.Z For. Serv., For. Res. Inst., Genet. and Tree Impr. Rep. 62* (unpubl.).

Uprichard, J. M; Corson, S. R.; Gray, J. T., 1972: Papermaking properies of mechanical and kraft pulps from *Pinus muricata. N.Z. For. Serv., For. Res. Inst., For. Prod. Rep. 427* (unpubl.).

Weston, G. C., 1957: Exotic forest trees in New Zealand. *N.Z. For. Serv., Bull. 13.*

——— 1966: The role of pine species other than radiata pine in New Zealand forestry. *Documents produced for For. Res. Inst. Symp. 7, 1966* (unpubl.).

Whiteside, I. D, 1972: Report on investigations into the commercial applications of machine stress grading at Waipa. *N.Z. For. Serv., Util. Devel. Div. Int. Rep. 20* (unpubl.).

Williams, A. L.; Bannister, M. H., 1962: Composition of gum turpentines from twenty-two species of pines grown in New Zealand. *J. Pharm. Sci., 51*: 970-5.