Native provenances of *Pinus radiata* in New Zealand: performance and potential

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Abstract

Provenance testing of Pinus radiata in New Zealand has run in parallel with an intensive breeding programme that exploited local 'land-race' stocks. The species was long known to occur at three places on the Californian mainland coast, Año Nuevo (Lat. 37°N), Monterey (36.5°) and Cambria (35.5°), but has since proved to include the pines of Guadalupe Island (29°) and Cedros Island (28°) off the Baja California Peninsula. Very limited provenance testing began in the 1950s, with comprehensive testing on a few sites in the mid-1960s, followed in 1980 by a countrywide series on 23 sites involving just the Californian mainland provenances. Different profiles of site adaptation among provenances have emerged. Año Nuevo and Monterey are the best adapted overall to New Zealand conditions, but Año Nuevo is much less adapted to P-deficient clays, yet better adapted to cold, snow-hazard sites. Cambria is susceptible to needle-casts, shoot dieback, and frost and snow damage, but has tolerated poor soils. Guadalupe, while showing some adaptational problems and slower growth as a pure strain, has very straight stems and 10% higher corewood density, and has given very promising hybrids with local stock. Cedros, as a pure strain, is much slower growing with severe adaptational problems, although hybrids have grown well. Local stocks are evidently 'mixtures' that have originated mainly from Año Nuevo (50-75%), the balance from Monterey.

To start the breeding with local stocks proved right, but native-provenance material still promises to make valuable contributions. In particular, Monterey material may boost edaphic tolerances, and Guadalupe hybrids may have a significant place.

Introduction

Pinus radiata breeding in New Zealand began on the two-pronged assumption that provenance variation would be unimportant and that local 'land-race' stocks would suffice as a genetic base, although a very limited provenance trial was planted on two sites in 1955 (Shelbourne *et al.*, 1979). Early provenance trial results in Australia (Fielding, 1961), while showing some provenance variation, endorsed the use of local stocks. Bannister (1959), however, stressed that the species was actually more widely distributed than previously thought, since it included the pines of Guadalupe Island and possibly those of Cedros Island as well. Thus it comprised no fewer than four and possibly five discrete natural populations (provenances) among which there were some marked differences. He postulated that by importing and intercrossing fresh material for future breeding purposes tree breeders could enhance adaptation to local conditions, give greater scope for long-term genetic gains, and confer additional flexibility should utilisation needs change in the future.

Accordingly, Bannister (1963) instigated a large provenance-progeny trial (Burdon and Bannister, 1973; Burdon *et al.*, 1992b), which was planted in 1964, -5 and -7 on two contrasting sites in Kaingaroa Forest. This contained 50 seed-parent progenies from each of the five native populations, Año Nuevo (Lat. 37°N), Monterey (36.5°) and Cambria (35.5°), on the Californian mainland coast, and Guadalupe Island (29°) and Cedros Island (28°) off the Baja California Peninsula. The inclusion of Cedros material as *P. radiata* has been vindicated (Burdon, 1992), although its slower growth posed major experimental problems (Burdon *et al.*, 1992b). This experiment, called the "Genetic Survey", thus sampled almost the full natural range of the species, and was designed to evaluate the genetic variability at the levels of populations, localities within populations, and individual trees. Also included were similar samples from two New Zealand populations (Kaingaroa and Nelson) that were thought to typify local 'land-race' stocks. Spare planting stock was used for three small trials designed purely to compare provenances at three other sites, Gwavas (Hawke's Bay foothills), Santoft (Manawatu sand dunes) and Golden Downs (Moutere gravels) (Shelbourne *et al.*, 1979).

At the same time, and since then, some inter-provenance hybrids were planted in tests, especially hybrids of the two island provenances with New Zealand material.

From the trials planted in the 1960s came a clear picture of the Californian origins of the particular local stocks, predominantly Año Nuevo (much the smallest of the Californian mainland populations) with the balance being Monterey. Thus the representation of the natural range of the species, within those Kaingaroa and Nelson stocks, was very incomplete and unbalanced. There were also indications that the under-represented Monterey provenance had some better soil tolerances, which was consistent with the existence of some infertile sites at Monterey, and with the presence of strong tree-to-tree variation in local stock in soil tolerances (Burdon, 1971, 1976). While the other populations showed considerable adaptive limitations as pure strains (Burdon, 1992), some of the inter-provenance hybrids were very promising, notably those involving Guadalupe and local stock.

It was decided to mount a further seed collecting expedition in California to allow far more thorough provenance testing of *P. radiata* in New Zealand, and to augment the available native-population gene resources. In 1978 a joint Australia-New Zealand expedition took place (Eldridge, 1978). New Zealand's involvement was confined to the Californian mainland stands of *P. radiata*, and from that New Zealand obtained unpedigreed seedlots from various locations within the native stands. The collection was used to establish countrywide provenance trials and some larger blocks of gene-resource plantings. This paper is concerned primarily with summarising results from those trials and discussing the future implications of them and the results from other trials of native-provenance material for New Zealand forestry. It is planned to publish the results elsewhere in much more technical detail.

Material and Methods

The 1978 collection produced seedlots from a total of 13 localities which were believed to represent ecological subdivisions of the populations (four, six and three at Año Nuevo, Monterey and Cambria respectively). On average, such seedlots represented bulked seed from 40 trees (range 22-70) in a locality, each locality having been grid sampled as far as was practicable. Three regional land-race stocks, 'Kaingaroa', 'Nelson' and 'Southland', were chosen to provide New Zealand controls, these being very predominantly from select-tree seed collections within supposedly unimproved stands. Of these, the Kaingaroa and Southland

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lots were undoubtedly representative of a number of stands (about 15 in Kaingaroa and six in Southland[-Otago]). The Nelson (Golden Downs) lot was drawn from a large multi-compartment seedlot, although the breadth of representation was uncertain.

Planting stock was raised in replicated layouts in two nurseries, Forest Research Institute, Rotorua, and Rangiora, the latter being used to supply planting sites outside areas that were officially infected with *Dothistroma pini.* Sowing was done in 1979 and outplanting in 1980.

Trials were planted on 23 sites scattered almost throughout the country (Fig. 1). Some extreme sites (infertile soils, high altitude, and low and high precipitation) were included, to provide a searching test of comparative site tolerances. Seventeen trials represented seedlots as six-tree row-plots with 12 replicates in randomised complete blocks. The remainder, at Pouto, Riverhead, Rotoehu, Kaingaroa, Berwick and Longwood, used large six-tree x six-tree plots, with 10 replicates except for five each at Berwick and Longwood.

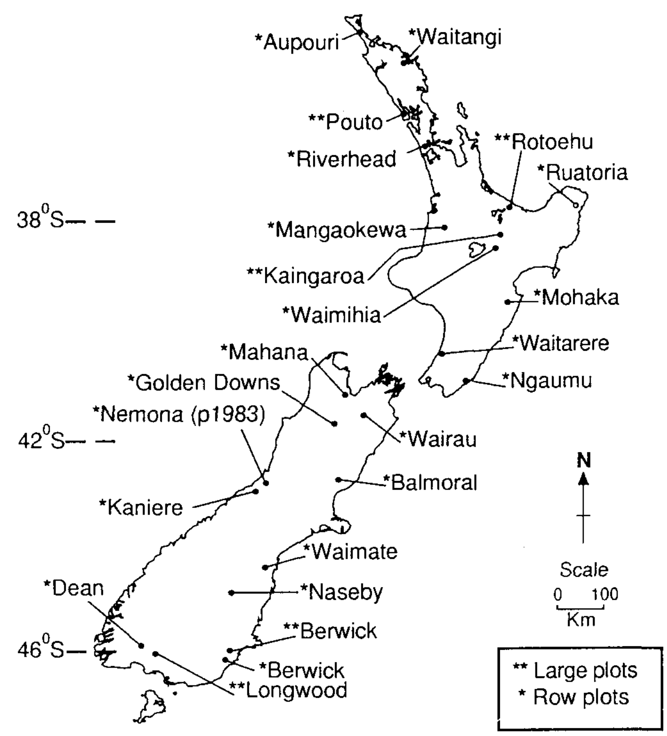

Figure 1. Map showing locations of trial sites.

After initial survival counts, and some early measurements in some trials, the first main assessment began at age five and a half from planting in the fastest-growing trial and extended through to age 11, in an attempt to assess the various trials at similar tree heights. Of the 22 trials, 16 had predominant mean heights between 7 m and 10 m, three slightly outside this range, and three below 6 m. Variables recorded on each tree almost always included: dbhob; bark thickness (samples only); height ('predominant'); survival; visual scores for stem straightness, branch cluster frequency and malformation (1-9); and stem acceptability (0 or 1). In addition to trees thus assessed, records were made of the occurrences of runts, hopelessly messy stems, and cases of climatic damage as far as causes could be identified. The levels of Dothistroma blight and Cyclaneusma needle cast were scored where readily feasible. Derived variables included plot basal area, in large-plot trials (as a proxy for stem volume per hectare), and incidence of 'successful' trees (surviving stems that were neither runts nor hopelessly malformed or seriously damaged, as a proportion of those that were planted).

At age 15 a follow-up assessment was made on seven of the trials and a first assessment finally made on the two in Westland, with the focus on dbhob and acceptability.

Data analysis was based on site-by-site analyses of variance, treating as random effects seedlots within provenances (providing a stringent test of provenance differences) and seedlots x replicates 'interaction' (in practice, plot-environment effects). Analyses of covariance were used, adjusting bark thickness for dbhob, and 15-year dbhob for preceding dbhob.

For presentation, provenance and seedlot means (least-squares) were converted to Relative Performance (RP) values setting trial means at 100 (cf Burdon *et al.*, 1992a), and assigning highest values to the most economically desirable expressions of traits. For percentage values or subjectively scored traits the RP values were independent of convention, e.g. choice of whether to express results in terms of ratios of mortality or of survival. Where appropriate, the RP values were set to symmetrical bounds of 0 and 200 to ensure that the overall average of seedlots or provenance RP values was close to 100 (Burdon, in MS).

At one site a complementary study (R.D. Burdon, P. Broekhuizen and J.A. Zabkiewicz, in prep.) involved detailed sampling of resin from all seedlots for comparisons of terpentine composition.

RESULTS

Success rates differed markedly among provenances on some sites but not others, depending largely on how difficult the particular sites were. In terms of success rate and growth performance there were strong differences among provenances in their RPs on different site categories (Table 1). These constituted obvious provenance x site interactions. These differences were most strongly expressed in terms of basal area/ha (calculated only for the large-plot trials) which encapsulated both success rate and growth performance, and were least expressed in height.

Table 1: Relative Performances of provenances averaged by site categories for success rate, height, diameter and basal area.

Site Category	No. of sites	Provenance			
		Año Nuevo	Monterey	Cambria	NZ
Height					
Infertile clays	2	95	105	96	101
Coastal dunes	3	100	99	96	103
Volcanic plateau	4	101	101	92	105
Central	4	102	99	94	103
Southern S.I.	6	103	98	93	102
Diameter					
Infertile clays	3	92	105	102	99
Coastal dunes	2	97	102	100	103
Volcanic plateau	4	97	102	93	106
Central	5	98	100	96	105
Southern S.I.	6	99	100	96	104
Success					
Infertile clays	3	83	113	106	94
Coastal dunes	3	114	96	84	123
Volcanic plateau	4	106	96	85	129
Central	4	108	99	87	114
Southern S.I.	7	130	90	69	120
Basal areas					
Infertile clays	1	68	121	109	91
Coastal dunes	1	96	103	99	102
Volcanic plateau	2	91	101	96	116
Southern S.I.	2	126	89	57	127

Infertile clays - Waitangi, Riverhead*, Mahana
Coastal dunes - Aupouri, Pouto*, Waiterere
Volcanic plateau - Rotoehu*, Mangaokewa, Kaingaroa*, Waimihia
Central - Ruatoria, Mohaka, Ngaumu, Wairau, Golden Downs
Southern S.I. - Balmoral, Waimate, Naseby, Dean, Berwick (1)*,Berwick (2), Longwood*

* Large-plot trial

The Año Nuevo provenance fared poorly relative to the others on the infertile clays but very well in the southern South Island. Monterey, by contrast, was the best-performing provenance on the infertile clays, producing almost double the basal area of Año Nuevo at Riverhead, but its worst RP values in the south. The New Zealand material performed best over most of the country, notable exceptions being the infertile clays, basal area/ha being 25% below that of Monterey at Riverhead.

Success is the summation of several factors, notably initial survival, the incidence of runts and hopeless multileaders, and freedom from severe climatic damage. On coastal dunes, the overall failure rates were low but large relative differences in incidence of such early multileaders generated divergent RP values which, however, were not reflected in the basal areas.

Relative Performance figures for resistance to specific agencies were based on data from a few sites where the problems were prevalent. They are shown for provenances in Table 2A. Cambria was clearly inferior in resistance to the two needle-cast diseases, uprooting by wind and snow, snow breakage, and snow damage in general. Monterey was also susceptible to the climatic damage although less than Cambria. Año Nuevo and New Zealand material generally showed well, Año Nuevo tending to excel in resistance to uprooting, and New Zealand in resistance to *Dothistroma* and snow breakage.

Tip dieback was deemed worth recording at only the two northernmost sites, Aupouri and Waitangi. Only at Aupouri did it show provenance differences, with Año Nuevo being clearly the most affected (RP = 80).

For tree-form traits (Table 2B) New Zealand material was generally superior, but Cambria excelled in stem straightness. Cambria, however, showed relatively high malformation. Año Nuevo, unlike New Zealand, showed a markedly lower frequency of branch clusters, particularly in the south (details not shown).

Differentiation among sub-populations of the native provenances was generally weak and, while not actually absent, was much less than many of the provenance differences described above, so details are not shown. Some differences, however, were evident among the New Zealand seedlots (Table 3). Branch cluster frequency score was lower in the Southland seedlot, at every site, compared with Kaingaroa. However, Southland showed better resistance to climatic damage. It also showed a slightly higher overall acceptability rate, with higher rates at the six southernmost sites, but *vice versa* at the four northernmost. Nelson showed somewhat higher success rates and a higher basal area on infertile clays than Kaingaroa and Southland.

The 15-year assessments, where made, generally confirmed the results reported above. However, on three sites where *Dothistroma* was prevalent the RP values of Cambria for dbhob and basal area had dropped sharply, basal area by an average of 15 percentage points, with compensating improvements for other provenances, especially Año Nuevo. At Pouto the RP of Cambria dropped slightly, but at Longwood, where thinning was not done, the figures for Año Nuevo dropped by around 10 points and those for Monterey and Cambria each rose by around five points.

On the poor 'gumland clay' soil at Waitangi, the Año Nuevo provenance lost further ground, although competition between row-plots could have contributed.

The associated study of resin composition (monoterpenes) confirmed Año Nuevo and Monterey as the progenitors of the New Zealand seedlot, indicating that Año Nuevo had contributed two-thirds to three-quarters of the genes of Kaingaroa and Southland, but slightly under half the Nelson genes. Bark thickness, which did not differ clearly among the New Zealand lots, indicated a 70% contribution from Año Nuevo (details not shown).

Table 3: Overall mean Relative Performance values for New Zealand land-race lots.

Trait	No. of sites	Land-race lot		
		Kaingaroa	Nelson	Southland
Branching frequency	18	119	118	105
Acceptability*	16	107	108	114
Uprooting resistance	5	99	96	109
Snow breakage	3	118	122	140
Total snow damage	3	101	107	116

* Among 'successful' trees

Table 2: Overall provenance means for Relative Performance values for provenances, for traits showing limited provenance x site category interaction.

Trait	No. of sites	Provenance			
		Año Nuevo	Monterey	Cambria	NZ
A: Adaptational traits (resistances)					
Dothistroma	3	108	104	71	122
Cyclaneusma	6	102	103	88	107
Uprooting •	5	133	91	84	100
Snow breakage	3	106	94	86	125
Total snow damage	3	124	90	81	104
B: Tree-form Traits					
Straightness	15	97	98	106	102
Malformation	17	103	98	92	109
Branching frequency	18	92	100	98	114
Acceptability †	14	99	96	96	112

• Including uprooting by snow

† Among 'successful' trees (excluding deaths, runts, extreme malforms and severely damaged trees)

DISCUSSION

The results generally agreed with those obtained overseas, particularly in respect of tolerances of infertile soils (Johnson *et al.*, in MS) and resistance to *Dothistroma* (Ades and Simpson, 1991). The extension to South Island snow-hazard sites, however, added an important dimension.

The finding of potentially greatest practical importance is confirmation of the soil tolerances of the Monterey provenance, which are evidently combined with good general adaptedness to New Zealand conditions except for colder and/or snowy sites in the south. The predominance of Año Nuevo in the ancestry of local stock bore out the earlier, independent results (Burdon, 1992), even in the difference between Kaingaroa and Nelson stocks.

The use of more Monterey material for the breeding programme has an obvious potential for conferring greater tolerance of 'gumland clays' and similar soils. While there is undoubted scope for selection for this attribute within local stocks we must note that the New Zealand material was substantially outperformed by Monterey on such sites despite evidently containing between a quarter and about a half of Monterey genes.

Moreover, screening on Northland clay sites, which would theoretically double the growth rate gains otherwise available from selecting within New Zealand stock for such sites (Johnson and Burdon, 1990), is hard to achieve, largely because the patchiness of the sites is not conducive to good progeny trials.

Indeed, it has long been appreciated that adaptation to gumland clay sites requires somewhat different tolerances from elsewhere in the country (Burdon, 1971, 1976). Little, however, has been done to capitalise on the selective pressures imposed by such sites. Poor cone yields there made select-tree seed collections very unattractive, and site heterogeneity and weed growth have discouraged plus tree selection and progeny testing there. However, some plus tree selection was done on Northland clay sites in 1987, and some progeny tests were established in the mid-1980s. Moreover, there are naturally invading populations in Northland and on similar soils south of Auckland which could show enhanced adaptation. It is suspected, from their success on such sites and from casual observation of general appearance and cone sizes, that they could carry very high percentages of Monterey-origin genes.

Afforestation now occurs on much better Northland clay sites than in the Waitangi and Riverhead trials, even though fertilisers and other forms of site amelioration can be used, which calls into question the need for such special soil tolerances. Against that, progeny rankings have been close to identical on two clay sites of widely differing fertility (Johnson and Burdon, 1990), although both were still less fertile than many that are now being planted in the region. However, the soil tolerances of Monterey material, if fully exploited, might lower the soil-quality threshold for economic afforestation.

It should also be noted that in the north of the country, even off the infertile clays, Monterey still performed well for diameter and basal area.

The soil tolerances of Cambria have fewer attractions, given its various adaptational problems. However, its tolerance of *Phytophthora cinnamomi* (Butcher and Stukely, 1986) and reported drought tolerance in Australia (K.G. Eldridge, *pers. comm.*) illustrate how an apparently unpromising provenance can have surprising attributes which might eventually be needed.

The good performance of Año Nuevo at high altitudes in the southern South Island is reassuring in view of its predominance in the ancestry of local stock, and argues against recruiting much Monterey material for breeding for such sites. Given the relatively quick maturation (physiological ageing) of Año Nuevo (Burdon *et al.*, 1992a), this endorses the still uninvestigated suggestion that cuttings with some maturation may have better snow resistance than seedlings. It also suggests that hybrids of Guadalupe trees may have good snow resistance, given both the rapid maturation of Guadalupe seedlings (Burdon *et al.*, 1992a) and the altitude and climate of the island (Libby *et al.*, 1968); in fact some hybrids have been planted experimentally on high-altitude, snow-hazard sites in New Zealand.

Guadalupe hybrids have shown 5% higher wood density and straighter stems than their New Zealand parents, and yet good growth rates and health (to be published). Cedros hybrids have also done very well (C.J.A. Shelbourne, unpubl.), but the extent of the adaptational problems of pure Cedros is a concern.

Action already taken on the results of testing provenances and interprovenance hybrids includes selection of around 200 superior trees from within the available native-provenance plantings near Rotorua. Some of the selections from the Californian mainland provenances are being incorporated into the long-term breeding population, to augment its genetic base. Over half these trees have come from the Monterey provenance, although none had grown on sites where Monterey shows its greatest superiority. Over 60 Guadalupe trees have been selected, with the additional aims of maintaining a select pure-provenance population and limited commercial production of hybrids of Guadalupe and select local stock.

In addition to having made such selections, it is still desirable to have native-population material 'in the wings', managed so as to improve silvicultural acceptability without really eroding other aspects of genetic variation (Burdon, 1995). The natural stands are seen as gene resources of last resort, but they are unimproved (if not dysgenic) silviculturally. The recent arrival of pitch canker in California, which can be transmitted by seed (Eldridge, 1995), is a twofold problem. It is an ominous threat to the stands, and it makes seed importations risky. Also there are regeneration problems in much of the natural range arising from a clash between urbanisation and the natural fire ecology. Yet the option of maintaining pure native-population stocks as gene resources in New Zealand is threatened by ubiquitous pollen contamination from plantations, unless massive controlled-crossing operations are practised. Indeed, the progressive replacement of the land races with intensively improved but quite narrowly-based stock would, through the pollen contamination, continue to erode the value of open-pollinated gene resources. Quantifying such pollen contamination is a research priority.

Adaptive genetic shifts, in response to natural and silvicultural selection since introduction, have been postulated. However, they are not the only possible explanation for superior performance of the New Zealand material. An obvious alternative, which had undoubtedly contributed, is a release from the neighbourhood inbreeding of natural stands. The most definite adaptive shift is towards more 'multinodal' branching, particularly in Kaingaroa. This accords with branch cluster frequency being consistently in a positive genetic correlation with growth rate (Burdon, 1992), especially on North Island sites. There were also indications that Kaingaroa and Southland tended to show better adaptation in the north and the south of the country respectively.

New Zealand material has, of course, had an additional head start in genetic improvement in a small element represented in the intensive breeding programme. However, its long-term genetic potential may be significantly short of that for the total species for a number of site types within the country. To be sure that the potential will be attainable, we need to maintain and manage genetic material that covers a wider native-provenance base than that of our traditional land-race stocks.

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TECHNICAL NOTES

The SMART method of assessing radiata timber

How best to use a given log? Is it suitable for lumber production, or should it go to pulp and paper manufacture? The best decisions are not always made, because traditional testing methods are time-consuming, cumbersome, and destructive.

But now Wood Products Division chemists have developed a new SMART method (it stands for Spectroscopic Modelling and Assessment of Radiata Timber) that allows them to assess the properties of logs cut from radiata pine trees in a fraction of the time taken by conventional tests. The more rapid screening opens up opportunities for better resource allocation decisions, as well as providing rapid feedback to tree breeders on a number of properties so they in turn can use the best tree breeds for further breeding.

The method is based on the absorption of infrared light by a sample of the wood. Normally, research chemists use this information to determine the chemical composition of the wood. It has been shown that by analysing a large number of radiata pine samples and using a statistical method to "calibrate" the instrument, it is possible to measure not only the amounts of various chemicals in the wood (sugars, resins etc.), but also the density of the sample. The advantage of the method is that all the information is obtained at once in about 10 minutes, as opposed to the one to two days it would normally take using conventional systems.

Investigations still in progress inicate that the method also has potential to predict the tendency for some lumber to form checks or fractures when dried at high temperature. Once it is possible to predict the lumber which is susceptible to checking, changes can be made to the drying process to minimise or eliminate the problem. This represents large savings by reducing the amount of reject lumber produced.

Work is also under way to determine if the method can be extended to measure wood strength and stiffness, and predict kraft pulp and paper properties.

The long-term goal of the project is to develop a tool for forest owners and log processors to assess a large number of tree and end-use properties. This will help forest owners assess their existing stands to optimise their end use, as well as helping tree breeders screen large numbers of clones to select the top performers.

Source: FRI