Five-Needle Pines in New Zealand: Plantings and Experience

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Abstract—Five-needle pines that have been tried as plantation crops in New Zealand are: *Pinus strobus* L., *P lambertiana* Dougl., *P. monticola* Dougl. *ex.* D. Don., and *P. wallichiana* A.B. Jacks. Total plantation areas have reached approximately 1,300 ha, 75 ha, 20 ha and 10 ha, respectively but have generally dropped in recent years. A partial picture of provenance variation in performance has been obtained. These species have grown well on a range of sites but have tended to be affected by drought and exposure. While they are sometimes affected by out-of-season frosts, the tolerance of partly continental conditions is generally good. Disease has been little problem, except for root disease in *P. strobus* on poorly drained soils and *Dothistroma* needle blight on *P. lambertiana* at some sites. However, animal damage (mainly deer and Australian possums) has often been troublesome and has led to much malformation. Productivity can be high, with mean annual increments of approximately 25 m^3/ha/year stemwood in *P. strobus* and *P. lambertiana*, and equal to or greater than 30 m^3/ha/year in *P. monticola*, given favourable sites and appropriate provenances. One other species, *P. ayacahuite*, has shown promise; while fairly frost-tender and prone to animal damage, it can have the fastest height growth and produce 24 m^3/ha/year or so in stem volume. Eight other species are known to have grown successfully in New Zealand without arousing commercial interest, and a few others have failed to grow. Despite some good performances, five-needle pines are eclipsed in New Zealand by Monterey pine (*P. radiata* Don.), Douglas-fir and some eucalypts. However, there has been a recent reintroduction of a provenance collection of *P. lambertiana*.

Key words: *Pinus strobus, Pinus monticola, Pinus lambertiana, Pinus wallichiana, Pinus ayacahuite*, provenance, genecology, growth, yield, site adaptation, browse damage, fungal diseases.

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History in New Zealand

Five-needle pines were first introduced into New Zealand well over 100 years ago, including: *P. strobus* in 1866, *P. wallichiana* in 1868, *P. lambertiana* in 1869; *P. monticola* in 1905 and 1907, and *P. ayacahuite* in 1915.

The first plantings were often few trees and mostly on private estates. Later plantings were more extensive, and predominantly within state forests, either as part of routine plantings or in designated research trials. Plantings have been mostly in the central North Island (Lats 37-39°S, Long. 176°E), but plantations have been established as far as 46°S. Elevations of planting have varied from near sea level to around 600 m, mainly in areas of 1,000 to 1,600 mm annual precipitation.

In the case of *P. strobus*, state plantings between 1931 and 1935 comprised more than 50 percent of the eventual total area. By 1957 there were 1,282 ha in pure stands (1210 ha in the North Island and 73 ha in the South Island), with 39 ha in mixture with other species. By 1960 there were estimated to be 1,307 ha under all ownerships, over 1,130 ha being in the central North Island. *Pinus strobus* has proved to be vigorously invasive in some localities. It has regenerated freely around Rotorua, spreading up to 3 km from the parent source into scrubland. It has also become naturalised in the South Island in Nelson, North Canterbury, and at Mt Linton (Lat. 46°S).

Plantings of *P. monticola* were small by comparison. State trials were planted in the North Island about 1910 and in the South Island in 1932 and 1933. Further experimental plantings occurred in the central and lower North Island between 1947 and 1958, and by 1961 the total area had increased to 21 ha of which 98 percent was in the North Island.

The main plantings of *P. lambertiana* took place in the central North Island between 1928 and 1931, with small areas being added in the South Island about the same time. By 1957 the total area of *P. lambertiana* in State Forests was approximately 74 ha, of which only 5 ha were in the South Island. By 1961 this was down to 68 ha, over 80 percent of which was in the North Island.

Small areas of *P. ayacahuite* were planted by the state forestry agency in 1915, and in species trials between 1957 and 1959. Further plantings were confined to provenance trials established between 1959 and 1963 at nine locations throughout the country.

Pinus wallichiana has been fairly widely planted in New Zealand but usually singly, as small groups as an ornamental, or with in species trials. By 1956 there were approximately 9 ha in State Forests, nearly all in Golden Downs Forest in the north of the South Island.

Other five-needle pines occasionally found growing satisfactorily in New Zealand arboreta include *P. flexilis* James, *P. aristata* Engelm., *P. peuce* Griseb., *P. koraiensis* Sieb. & Zucc., *P. cembra* L., *P. maximartinezii* Rzedowski, and *P. morrisonicola* Hayata.

A species that failed was *P. chiapensis* (Martinez) Andresen. Planted in two North Island trials, it suffered heavy initial losses from frost, and then succumbed to browsing by the Australian brush-tailed possum (*Trichosurus vulpecula*).

Little record exists of the seed origins of New Zealand white pine imports. Seed for some of the *P. strobus* plantings of the 1920s came from Ontario in Canada. Seed of *P. monticola* was imported from interior British Columbia in 1927 and from a Washington, USA, supplier in 1941. A small amount of *P. lambertiana* seed came in 1869 from a San Francisco supplier, but the sources of other early importations are unknown. Origins of seed imported by the Forest Service between 1927 and 1930 included Butte, Eldorado, and Placer Counties in California, and, in 1947 and 1948, from the northern Sierra Nevada of California and the southern Cascades into Oregon.

In recent years the areas of plantings of five-needle pines have declined sharply, largely through widespread replacement with the Monterey pine (*P. radiata*).

Site Tolerances

Most of the five-needled pines grown in New Zealand can tolerate a wide range of local soil types. However, they prefer fertile, moderately deep and well-drained soils, with poor drainage favouring root disease. While fastest growth, particularly in early years, tends to occur on warm, mild sites, and out-of-season frosts can be damaging, the temperate species tolerate well the partly continental conditions of the central South Island. Drought, particularly on poor soils, can be associated with mortality, and tolerance of exposure tends to be limited.

Pinus monticola, P. lambertiana, P. flexilis, P. aristata, P. cembra and *P. peuce* have been planted in the Craigieburn Ranges (Lat. 43°S) in Canterbury. Although growth over early years was often slow, on the better sites below 1,000 m elevation (above sea level) they have generally been healthy, of good form and have performed consistently. At higher altitudes and on depleted soils there has been poor survival. Here it should be noted that timberline in New Zealand is low in relation to latitude.

Pinus strobus

In New Zealand *P. strobus* tolerates a fairly wide range of sites and climatic conditions including poorer dry sites but grows best on moderately fertile, deep, fresh soils. It has grown particularly well in damp, sandy, deep soils adjacent to streams in Canterbury. Reasonably good shelter is preferred and *P. strobus* is generally unsuitable for too exposed sites. It has grown successfully at elevations of 60 to 900 m in the North Island and 60 to 600 m in the South Island. Early growth is generally quite slow, requiring control of weed growth on fertile sites. It grows best in full light when young but some shade is tolerated.

Pinus monticola

Pinus monticola has been tried mostly in cooler parts of the North Island and northern South Island with annual rainfall of 760 to 2,030 mm, and appears to be the least demanding species. It is hardy and has withstood –14°C of frost. It has grown well on pumice soils in the central North Island and will also tolerate fairly poor drainage and rather sour clay soils. It has succeeded at elevations of 60 to 670 m in the North Island and 275 to 410 m in the South Island.

Pinus lambertiana

This species has been planted in the central North Island, Wellington, Canterbury, and Otago in localities with annual rainfall of 760 to 1,650 mm. Establishment has often been slow and variable. Young trees need shelter for successful establishment and on exposed sites they can be checked or killed by frosts. It failed at Hanmer (Lat. 43°S, elevation approximately 400 m) due to frost; however, older trees have withstood frosts of –14°C. *Pinus lambertiana* has succeeded on well-drained pumice soils in the central North Island where optimum growth and form occurred at 300 m elevation. In Canterbury it has grown strongly in well-drained, sandy or silty sites but cannot tolerate waterlogging, while older trees growing on dry shingly soil at Greendale in Canterbury have died, probably due to drought. It has been reported to favor alkaline soils.

Pinus wallichiana

Pinus wallichiana has been tried in Wellington, Nelson, and Canterbury within a rainfall range of 760 to 1,400 mm and has grown well on fertile, alluvial soils and light loams with adequate moisture. It is relatively wind-tolerant, but growth is poor on exposed sites, and trees in a trial at 490 m in Kaingaroa Forest were badly malformed. The species is hardy and has withstood frosts of –14°C.

Pinus ayacahuite

In most New Zealand trials of *P. ayacahuite* growth and survival have been poor. Frost damage occurred when the trees were young, and they proved susceptible to possum damage. On some sites, however, growth is excellent.

Pests and Diseases

Five-needle pines grown in New Zealand have generally been free of serious pests and diseases. The white pine blister rust fungus (*Cronartium ribicola* J.C. Fisch.) is absent. Even if it did arrive, the absence in forests of naturally occurring alternate hosts (*Ribes* spp.) should make it unimportant, although the genus *Ribes* does occur as some orchards and a few naturalised populations. Poorly drained soils tend to be associated with attack by root pathogens. Among other pathogens, the root-rot fungi, *Armillaria* spp., can affect most species, *Diplodia* sp. can kill occasional shoots, and *Dothistroma pini* can cause severe needle cast, depending on species and site. Various insect pests have

been recorded on five-needle pines; they are usually unimportant, but the wood wasp *Sirex noctilio* can sometimes cause significant mortality. Browsing damage by mammals (especially deer, goats, and possums) has tended to be troublesome on almost all species, but the phenomenon of preferential attack of minority species may well have been an important contributing factor.

Pinus strobus

The root-disease fungus *Leptographium procerum* (previously *Verticicladiella procera*) has been involved in considerable mortality of *P. strobus* in New Zealand. However, it is mostly associated with sticky, poorly drained soils and sometimes with root damage associated with road and access track construction. The foliage of infected trees becomes light green before wilting and turning rusty brown, and a black stain appears in the roots and the wood at the base of the trunk. The root-rot fungi, *Armillaria* spp., have been recorded from the roots and butts of *P. strobus.* The needle-cast fungi*, Dothistroma pini* and *Cyclaneusma minus*, have both been recorded from the foliage but not as significant pathogens. Other minor disease-causing fungi recorded for *P. strobus* include *Diplodia* spp., *Hypoderma* sp., and *Lophodermium* sp.

In New Zealand various insect pests have been recorded as present but not usually troublesome on *P. strobus*. *Sirex noctilio*, with its fungal symbiont, has caused damage in thinned stands.

Pinus monticola

In New Zealand *P. monticola* has generally been healthy and there are few recorded pest and disease problems. Disease-causing fungi recorded include *Armillaria* spp. (apparently troublesome in provenance trials but not in plantations), and *Dothistroma pini, Diplodia* sp., *Leptographium* sp., *Lophodermium* sp. and *Rhizosphaera* sp., generally as minor pathogens.

Pinus lambertiana

Dothistroma needle blight can cause severe defoliation on trees of *P. lambertiana* on New Zealand sites with summer humidity. *Cylindrocladium scoparium* has caused troublesome root rot in 2-year-old nursery stock. Otherwise, fungal pathogens and insect pests are generally unimportant.

Growth and Yield

Available growth data from a selection of measurement plots are summarized for different species in tables 1 and 2. They cover a range of latitudes, although latitude is not critical in itself. Elevations varied but none were extreme. Stem volume production could be high, despite modest height growth. Data from other sources are also considered below.

Pinus strobus

In New Zealand early growth generally rates as slow, but *P. strobus* is ultimately capable of high stem volume production with mean annual increments (m.a.i.) at 35 to 40 years ranging up to over 24 m^3/ha/year, depending much on site quality. Near Rotorua (Lat. 38°S), 50-year-old unthinned stands on good sites planted at 2,224 stems/ha had mean top height (m.t.h.) of 30 m, a mean diameter at breast height (d.b.h.) of 25 cm, a volume of 1,220 m^3/ha and a m.a.i. of 24.4 m^3/ha/year (Weston 1957). Mean top height is defined as the mean height of the 100 largest diameter trees per hectare. Small piece sizes can limit recovery rates: the 39-year-old stand with a total volume of 927 m^3/ha (table 1) had a recovered volume of 795 m^3/ha. Higher productivity could be expected with optimal provenances (see later).

Pinus monticola

In New Zealand *P. monticola* has, on the whole, grown slightly faster than *P. strobus*, with observed m.a.i. ranging up to equal or greater than 30 m^3/ha/year (table 1). In the early years annual height growth is generally 0.3 to 0.6 m. At Patunamu (Lat. 39°S), a fertile, low-elevation site, mean top height of 16-year-old trees was 15.8 m and the largest tree was 32 cm in diameter at breast height. In species trials in inland Canterbury (Lat. 44°S), a few 17-year-old trees averaged 7.9 m in height. In Kaingaroa Forest (Lat $38^1/_2$°S, elevation 488 m), a 22-year-old unthinned stand carried a total volume of 108 m^3/ha (m.a.i.= 5 m^3/ha/year) in 587 stems with m.t.h. of 15 m and a mean d.b.h. of 19.6 cm.

Pinus lambertiana

In New Zealand, on favorable sites, height growth of *P. lambertiana* in early years is 0.3 to 0.6 m annually. In well-stocked stands, trees in the upper crown classes are of good form; however, the proportion of double-leadered trees tends to be high, greater than 50 percent in some areas. At low stockings, especially on fertile sites, stem taper can be severe. On a site of moderate quality in Kaingaroa Forest (Lat $38^1/_2$°S), a 26-year-old stand (containing about 40 percent of malformed stems) has produced an estimated total volume of 452 m^3/ha (m.a.i.= 17.4 m^3/ha/year) in 1268 stems/ha averaging 13 m tall and 29.5 cm d.b.h. In a small plot on a good site nearby, the best dominant trees grew to about 27.4 m in height and 63 cm d.b.h. in 48 years (Weston 1957); at age 59 the same stand had a m.t.h. of 39.6 m, and a mean d.b.h. of 38 cm with 30 percent malformed, the largest tree being 89 cm d.b.h. A stand in lowland Canterbury (Lat. 44°S) on relatively dry fluvial gravels (precipitation approximately 700 mm/annum), planted in 1931 at 400 stems/ha, with stocking 260 stems/ha remaining, had a basal area of 12.5 m^2, a mean d.b.h. of 39 cm and a mean height of 11.9 m. Height growth was uniform but the trees were rough at this low stocking. Individual trees over 60 years old have reached 35 m height and around 100 cm d.b.h.

Table 1—Growth and yield of—*Pinus strobus*, *P. monticola*, *P. ayacahuite* and *P. lambertiana* in New Zealand[a].

Species	Age (yrs)	No. of plots	Stems/ha	D.B.H. (cm)	Ht (m)	BA (m^2/ha)	Volume (m^3/ha)	MAI/yr (m^3/ha)	Latitude (°S)
Pinus strobus									
Age 20-29 yrs	22	6	350	30.2	14.6	19.8	124	5.6	40
	27	4	920	33.1	19.4	41.7	331	12.3	38
	28	1	459	48.8	20.3	46.4	316	11.2	38
	28	1	1156	36.4	20.0	79.4	557	19.9	39 1/2
		mean	721	37.1	18.6		332	12.2	
Age 30-39 yrs	34	1	1416	29.2	17.8	51.9	251	7.4	46
	36	1	287	48.7	30.3	42.7	513	14.2	39
	38	1	1211	34.0	17.3	65.6	515	13.5	46
	39	1	1538	-	-	88.3	927	23.8	38
		mean	1113	37.3	21.8	62.1	551	14.7	
Age 40-49 yrs	41	1	1800	32.0	18.5	90.4	772	18.8	46
	42	1	2743	29.5	21.3	102.4	861	20.5	46
	43	1	1495	40.4	23.5	99.6	923	21.5	46
	44	1	1424	42.8	28.5	88.2	999	22.7	38
	45	3	626	44.7	28.5	56.3	638	14.2	38 1/2
	46	4	644	46.0	27.2	66.2	666	13.9	38 1/2
	48	1	1139	40.0	25.3	88.1	810	16.9	38
	48	1	941	45.1	25.4	78.3	833	17.3	38
		mean	1351	32.2	21.2	83.7	813	18.2	
Age 50-59 yrs)	52	2	607	46.5	27.1	63.9	673	12.9	38
	53	3	909	41.9	26.0	60.0	622	11.7	38
	53	3	946	38.1	22.1	67.4	947	17.9	43
	56	1	356	48.5	31.0	47.4	580	10.4	38
		mean	704	43.7	26.5	59.7	705	13.2	
Age 60 yrs +	62	3	784	51.8	35.1	93.3	960	15.5	38 1/2
	61-65	1	593	49.5	28.3	80.1	720	11.4	46
	69	4	694	50.5	34.8	75.7	1035	15.0	38 1/2
		mean	690	50.6	32.7	60.4	905	14.0	
P. monticola									
Age 30-39 yrs	34	1	949	39.5	17.7	53.6	371	10.9	38
	34	1	1480	36.3	18.5	86.6	624	18.4	39 1/2
		mean	1215	37.9	18.1	70.1	497	14.6	
Age 40-49 yrs	49	1	476	49.7	33.8	63.1	1560	31.8	38
P. ayacahuite									
Age 30-39 yrs	34	1	1400	45.3	23.4	116.4	863	25.4	39 1/2
	36	1	536	55.6	33.8	73.0	792	21.9	38
		mean	968	50.4	28.6	94.7	827	23.6	
P. lambertiana									
Age 30-39 yrs	36	1	536	53.4	20.5	62.5	406	19.2	38
	39	1	1183	63.2	21.2	156.4	1068	27.4	39 1/2
		mean	58.3	20.8	109.4	737	23.3		

[a] Source: New Zealand Forest Research Institute Ltd permanent sample plot system.

Table 2—Summary figures (mainly from table 1) for mean annual volume increment and mean height growth, by species.

Species	Total plots	Mean annual increment—stemwood (m^3/ha/yr) (>30 years old) Range	Mean	Height growth (m/yr) (Range)
P. strobus	30	7-24	15.5	0.42-0.84
P. lambertiana	2	19-27	23.3	0.54-0.57
P. monticola	4	11-32	20.4	0.52-0.99
P. wallichiana	2	-	-	0.42-0.48
P. ayacahuite	2	22-25	23.6	0.69-0.94

Pinus wallichiana

At Golden Downs Forest (Lat. 41½°S), a 21-year-old unthinned stand with about 1,000 stems/ha developed evenly, with tree heights 9 to 12 m and average diameter about 15.2 cm. In lowland Canterbury (Lat. 44°S) trees measured at 17 years averaged 8.2 m tall, while farther inland a few trees in species trials averaged 7.6 m in height at 18 years. An exceptional specimen, in the North Island, was 38.6 m tall with a d.b.h. of 105 cm when felled.

Wood Properties and Uses

New Zealand-grown timber of *P. strobus* tends to be slightly less dense than that from its native habitat, but otherwise the properties are similar. The relatively low density (370 kg/m^3 at 12 percent moisture content), low strength, and poor nail-holding ability make *P. strobus* unsuitable for structural purposes. Indications are that end joints machine poorly. Uniform texture and dimensional stability allow certain specialist uses, however, including ice cream spatulas and similar products, and for toy making, shoe heels, picture frames, and rulers. Its good woodworking properties make it useful for panelling. Timber assessed in pilot studies was seriously degraded by the frequent small encased knots, with insufficient lengths free of defects; this largely reflects the relatively short rotations that are deemed to be economic in New Zealand.

Pinus strobus has a large percentage of heartwood that has a high moisture content, leading to drying and seasoning difficulties, requiring relatively long drying times in either the kiln or open air. Drying is further complicated by the development of an irregular brownish stain resulting from enzymes acting on the sugars in the wood. Compared with *P. radiata,* the high proportion of heartwood in *P. strobus* renders it unattractive for pulping and also makes the product difficult to season and preserve for use as posts.

Timber tests on *P. monticola* (Harris and Kripas 1959) have indicated a general similarity to imported American material, including early formation of heartwood (34 percent at 24 years) and a high moisture content in the heartwood.

Establishment and Silviculture

Five-needle pines, while often being vulnerable to exposure, often need vigorous weed control for satisfactory establishment and good early growth in New Zealand. Usually the preferred way to achieve this is by the use of chemical sprays, best practice depending very much on local conditions. Good control of browsing animals is also important.

In general, five-needle pine stands in New Zealand have tolerated high stockings, with little difference between heights of dominant and other trees, yet only moderate mortality from mutual suppression. However, in dense stands the crowns are small, leaving long lengths of stem with persistent dead branches. Response to delayed thinning appears to be rather slow.

Although the five-needle pines in New Zealand are monocyclic or 'uninodal', the knot clusters are typically too closely spaced and far too persistent to yield the relatively long' 'internodal' clear-cuttings grades that have come readily from *P. radiata*. Because of this and their low wood density, standard silvicultural regimes do not exist. Appropriate regimes, if the species are to be grown further, would be governed by some largely conflicting considerations, including the desirability of early pruning to produce clear timber; the desirability of maintaining high stockings to realize the inherent productivity; and the time required to obtain clear timber from pruning, particularly if stockings are kept high.

Stem forking has been notorious in *P. strobus* in Southland. This is assumed to be due to wind, snow, and unseasonable frosts, but it could also be attributable in part to both animal damage and genetic origin.

High initial stocking for *P. lambertiana* also allows for selection of good-form trees at mean top height 15 m or later. The unusual ability of this species to sustain a high rate of growth to advanced ages argues for long rotations that, however, would make effective growing costs high by local standards.

Provenance Variation and Genetic Improvement

Provenance testing is the only level at which within-species genetic variation has been studied. Some limited cross-referencing of species has been done within provenance trials. Tree-to-tree genetic variation is not obvious in the way that it is in *P. radiata*.

Pinus strobus

Provenance trials were planted in 1970 with 77 seedlots of *P. strobus* on three New Zealand sites: Rotoehu (Lat. 38°S) and Gwavas (Lat. 39¾°S) in the North Island, and Golden Downs (Lat. 41½°S) in the South Island. Seed was provided by various suppliers in the United States and represented a fairly complete sample of the geographic range of the species (Lats 34½-48°N), albeit weighted toward the southern part. (Note: One lot was recorded as having been collected from 54°N in Manitoba, outside the limit of 52°N shown by Critchfield and Little (1966), but without appearing to be an outlier for growth rate). Ten-tree row-plots were used. Heights were measured at ages 3 and 5 years from planting (Shelbourne and Thulin 1976), while diameters and incidence of malformation were assessed at Rotoehu and Gwavas at 18 years, in 1988 (Chen 1989). Six seedlots of *P. monticola* and one of *P. wallichiana* were also included.

The early heights were closely correlated (negatively) with latitude of origin, the southernmost provenances being almost twice as tall as the northerly ones (Lat. ≥45°N) (Shelbourne and Thulin 1976). This was essentially irrespective of planting site, provenance x site interaction being only minor despite marked differences among sites at that stage. In fact, the estimated genetic correlation (compare Burdon 1977) between year-18 diameter across the two sites and latitude of origin was equal to or greater than 0.9. Thus most of the best provenances were from the south of the species' range; from the southern Appalachian region, northern Georgia, western North Carolina, West Virginia, and eastern Tennessee. These trees at 18 years averaged up to 30 percent greater in diameter than the overall mean, and had

higher survival and less forking. This pattern matched closely the results of Sluder and Dorman (1971) in a trial in the southern Appalachians. However, heights of provenances from the New England States were about the same as those from Virginia, Maryland, and Pennsylvania – that is, 7 to 10 percent above the overall mean for provenances from the same latitudinal range.

Consistency of provenance rankings within the three assessments suggested that early selection of *P. strobus* is possible at ages 3 to 5 years from planting, at least at the provenance level. *Pinus monticola,* and *P. wallichiana* had the poorest growth over all sites.

Some of the results remain puzzling. While the southern Appalachian provenances promised significantly greater productivity in New Zealand than Ontario material, the local seedlots from Kaingaroa Forest performed markedly better than their reported origins in Ontario would suggest, even allowing for any likely effects of both release from the neighbourhood inbreeding of natural stands and natural selection in the New Zealand environment. Thus, the reported origins from the Ontario region come into question. Generally, growth was best at two milder North Island trial sites, suggesting by itself that a higher altitude and warmer climate are more suited to this species.

The relatively poor showing of the *P. monticola* provenances included in these trials was also puzzling, in the light of stand growth data (tables 1 and 2). However, the lack of 18-year height data prevented rigorous testing of the hypothesis that the slower early growth of the *P. monticola* was a transient phenomenon.

Pinus monticola

Provenance trials were established using seven seedlots of *P. monticola*, comprising five native provenances collected by a New Zealand operator in 1956, plus one from the Institute of Forest Genetics at Placerville and another from a stand in Kaingaroa Forest. The native provenances came from the Sierra Nevada (as far south as $38^1/_2$°N), and the Southern Cascades, extending as far north as Lat. $45^1/_2$°, elevations ranging from 425 m to 2,300 m. They were planted out at three South Island sites in 1963 and four North Island sites in 1964. In addition four demonstration rows were planted out at Rotorua. The provenance from Kaingaroa Forest, derived from selected parent trees within an approved seed stand (N.Z. Forest Service), which reportedly originated in interior British Columbia, grew best among the tested origins, and was obviously well adapted. No formal assessments have been carried out, but inspection notes and observation of the demonstration planting revealed a strong pattern of inverse relationship between height and elevation of origin, within that part of the natural range. This pattern contrasts strongly with the weak elevational differentiation reported for the species in Idaho (Anon. 2000). Also surprising, in the light of provenance tests for various other species, were the indications that material originating from British Columbia was among the most vigorous samples. A suspicion arises that material from the part of the native range sampled for the provenance trials may be relatively prone to *Armillaria* root rot. *Pinus monticola* in general maintained better stem form than *P. strobus*.

Pinus lambertiana

Seven provenances were tested in trials established in 1960 to 1961 at nine New Zealand sites (two North Island, seven South Island; Lats 38-46°S). The seedlots used were collected from localities in California ranging in mean elevation from 850 m (1.6 km southeast of Koberg) to 2,000 m at Jordan Peak in Sequoia National Park.. Five of the trials remained current by 1999, showing, as expected, considerable within-population variation in tree size. Inspection notes from well-grown trials in each island showed that the relatively low elevation (760 to 1,030 m) seedlot from Lassen National Forest in northern California yielded trees with the best height and diameter growth.

In 1997 a wide provenance range of *P. lambertiana* seed was obtained from the United States. A total of 279 single-tree progenies representing eight provenance groups were sown in the research nursery at Rotorua in September 1977. Coastal Californian, and certain central Sierra lots showed vigorous early growth and good survival in the first 18 months in the nursery bed. However, other lots from the central Sierra area were among the poorest in growth and survival among this material, pointing to the necessity of further testing over time.

Pinus wallichiana

Little information is available on genetic variation in this species, and it has not been planted in provenance trials in New Zealand. One seedlot of *P. wallichiana* from a single tree was included in the provenance trials of *P. strobus* planted in 1970. At age 18 years, survival of this lot was comparable to *P. strobus* (about 70 percent), but diameter was 18 percent less than the mean of the 77 *P. strobus* lots in the trials. The only other known planting in New Zealand of *P. wallichiana* is as a forest stand of 9 ha planted in 1932 through 1938 at Golden Downs Forest (Lat $41^1/_2$°S) and in arboretum-scale plantings in inland Canterbury in the South Island (Lat. $43^1/_2$°S).

Pinus ayacahuite

Ten provenances of *P. ayacahuite* from locations in Mexico and Guatemala were planted at each of nine New Zealand locations between 1962 and 1968. Most plantings survived poorly and grew slowly, with high malformation rates mainly due to browsing by possums, and most were abandoned. Exceptions were two trials at Kaingaroa Forest and two at Gwavas Forest (Lats 38-$39^1/_2$°S). Survival at the best of these were over 90 percent and the average diameter in 1983, at age 15 years, was 20 cm. Although the incidence of multileadering was high, much of this could have been corrected by thinning. There was little provenance variation in growth.

Two plots of *P. koraiensis* were incorporated in a trial in Karioi Forest, at over 700 m elevation, in 1968, but all trees were killed by frost.

Future Roles in New Zealand

Despite often excellent growth by standards of natural ranges, ability to thrive on a range of sites, and resistance to certain diseases, five-needle pines are not foreseen as having any major role in New Zealand, because they suffer so much by comparison with the preferred species *P. radiata*, Douglas-fir, two cypresses, and various eucalypts. The required long rotations, plus some other factors that increase effective growing costs, in conjunction with limitations of timber quality and limited site tolerance all mitigate against any important role, even with use of better provenances.

Pinus monticola, despite lesser heights in some trials, emerges preferred over *P. strobus* in New Zealand because of its generally good growth and form (less stem forking) and its tolerance of difficult sites. *Pinus lambertiana,* despite its attractions as a virgin timber in its native sites and its high long-term productivity, is seen as seriously disadvantaged by a need for long rotations. *Pinus ayacahuite*, despite its growth rate, appears to be to site-demanding, apart from its timber being unproven.

A major collection of *P. strobus* remains, but the 'land races' represented in the commercial plantings have largely disappeared. However, a significant genetic collection of *P. lambertiana* has recently been established.

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