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Alternatives to *Pinus radiata* in the New Zealand high-country: early growth and survival of *P. radiata*, *P. attenuata* and their F_1 hybrid.

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Abstract

Fifteen families of each of *Pinus attenuata* × *P. radiata* hybrids and their open-pollinated pure-species controls were tested across three trial sites in the South Island of New Zealand. These hybrids were produced to combine the cold and snow resistance of *P. attenuata* with the faster growth of *P. radiata*.

At ages four and eight, the hybrids were the tallest taxon at the two semi-continental sites and had the most acceptable crop trees when compared with the pure species. At the mildest site, *P. radiata* was the tallest and *P. attenuata* was the shortest. After an exceptional snowfall, snow damage was recorded to be the greatest in *P. radiata*, *P. attenuata* had the least, and the hybrids had damage recorded which was intermediate between the two parent species.

The *P. attenuata* × *P. radiata* hybrid offers a real alternative to pine species that are prone to spreading (e.g. *P. contorta*) in the New Zealand high country.

Keywords: early growth; high-country; hybrids; inter-specific hybrids; New Zealand; *Pinus attenuata; Pinus radiata;* snow damage.

Introduction

In New Zealand, the viability of high-country pastoral farming has been declining. As a direct result, there has been increasing interest in afforestation of these areas (Hughes, 1991; Belton, 1993; Ledgard, 1999). The majority of these pastoral farms are in the inland areas in the South Island, particularly around the semi-continental regions of the McKenzie basin and inland Otago, where annual rainfall averages around 430 and 525 mm per annum respectively (New Zealand Institute of Water and Atmospheric Research, 2007).

Pinus radiata D.Don is the dominant plantation species in New Zealand, representing just under 90 percent of the current plantation area (Anon, 2009; National Exotic Forest Description, 2006). This species grows well in the areas of New Zealand dominated by a maritime climate, where rainfall is either uniform or largely winter-biased and where there are no extremes of low temperatures and minimal snowfalls (Lavery & Mead, 1998; Burdon, 2000). *Pinus radiata* would be a poor commercial choice on the semi-continental pastoral sites described above as it grows too slowly in these cold and dry environments (Miller & Knowles, 1988). Alternatives to *P. radiata* are needed. One alternative

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is hybrids of *P. radiata* with *P. attenuata* Lemmon, knobcone pine. *Pinus attenuata* is both drought and snow tolerant, frost tolerant and capable of growing on poor soils (Miller & Knowles, 1988). *Pinus attenuata* is highly susceptible to the needle disease caused by *Dothistroma pini* Hulbary, particularly in the central North Island (Miller & Knowles, 1988, T. G. Vincent unpublished report). However, in the South Island in the colder, drier areas, this needle disease is normally not present and therefore does not usually affect growth. Pure *P. attenuata* grows much more slowly on most New Zealand sites where commercial forests are grown, when compared with *P. radiata* (Miller & Knowles, 1988) but in some areas where *P. radiata* is unsuitable due to cold, snow and frost damage a hybrid between the species may offer the drought, snow and frost tolerance of *P. attenuata,* whilst retaining the faster growth rates possible with *P. radiata.* Such a hybrid would provide a valuable afforestation option for New Zealand's South Island high country.

Review of past studies

A small number of *P. attenuata* × *P. radiata* hybrids have been tested in New Zealand. Details of trial sites used are given in Table 1 and their locations are shown in Figure 1. In 1961, a provenance trial of *P. attenuata* was planted in Naseby Forest in the South Island. Along with the *P. attenuata,* the trial contained one seedlot of *P. radiata*, one *P. attenuata* × *P. radiata* and one *P. attenuata* × *P. radiata* backcross (wind pollinated) to *P. attenuata* (J. T. Miller, unpublished report). The trial comprised four replicates of 49 seedlots. Individual seedlots were represented by 16-tree plots (2 × 8 rows), except for three plots of *P. radiata*, which were represented by 32-tree plots. The trial design was randomised complete block. The 46 provenance seedlots of *P. attenuata* were all North American in origin, i.e. from the Santa Cruz (3), Coast Range (9), Southern California (3) and Northern Californian/Oregon (20) and Sierra Nevada (8) origins. In addition, one seedlot of *P. attenuata* from planted stands, of unknown origin, and an impure *P. attenuata* seedlot, containing some hybrids from El Dorado County (Sierra Nevada), was also tested.

At age 16 from planting, the *P. attenuata* × *P. radiata* hybrids were significantly taller and had a larger diameter (height 10.9 m, diameter at breast height [1.4 m] (DBH) 23.7 cm) than almost all of the pure *P. attenuata* tested (height 4.2 – 8.5 m; DBH 10.0 – 19.3 cm), and the backcross population (height 8.6 m, DBH 17.9 cm). The hybrids were not, however, significantly taller than the *P. radiata* seedlots, but had a significantly smaller diameter at breast height (J. T. Miller, unpublished report).

In 1978, progeny representing *P. radiata* × *P. attenuata* and *P. attenuata* × *P. radiata* putative hybrids were planted at three high-altitude South Island sites marginal

TABLE 1: Individual site location and predicted climate details. All climate figures are given as monthly means and were obtained from 30-year averages based on BIOCLIM (T. Paul personal communication, 2007; Busby, 1991).

Place name	Latitude (S)	Longitude (E)	Average no. days with ground frost per year	Mean annual rainfall (mm)	Mean daily temperature (°C)	Mean daily minimum temperature (°C)
This trial series (1998)						
Balmoral Station	44° 02′ 24″	170° 24′ 17″	139	567.65	9.03	3.69
Ribbonwood	44° 22′ 08″	169° 49′ 40″	131	905.19	6.74	1.97
Eyrewell	43° 23′ 46″	172° 16′ 33″	81	790.05	11.19	5.32
Mount Barker	43° 20′ 58″	171° 35′ 45″	99	826.55	9.65	4.53
Other sites *(includes previous trials in 1961 and 1978)*						
Molesworth	42° 10′ 33″	172° 56′ 00″	163	1532.83	7.39	1.87
Craigieburn	43° 08′ 59″	171° 42′ 49″	130	1411.99	7.91	2.55
Naseby Forest	45° 00′ 24″	170° 05′ 41″	133	620.99	8.18	2.37
Kaingaroa S.O.*	38° 28′ 02″	176° 32′ 36″	86	1292.38	10.77	5.40
Rangiora	43° 17′ 54″	172° 33′ 27″	61	723.61	11.54	6.13
Scion nursery	38° 09′ 18″	176° 16′ 01″	62	1502.51	12.88	8.27
Gwavas S.O.*	38° 43′ 52″	176° 24′ 03″	53	1328.18	10.95	5.76
Eyreton Nursery	43° 25′ 34″	172° 30′ 30″	67	684.02	11.54	6.08

* S.O. = seed orchard

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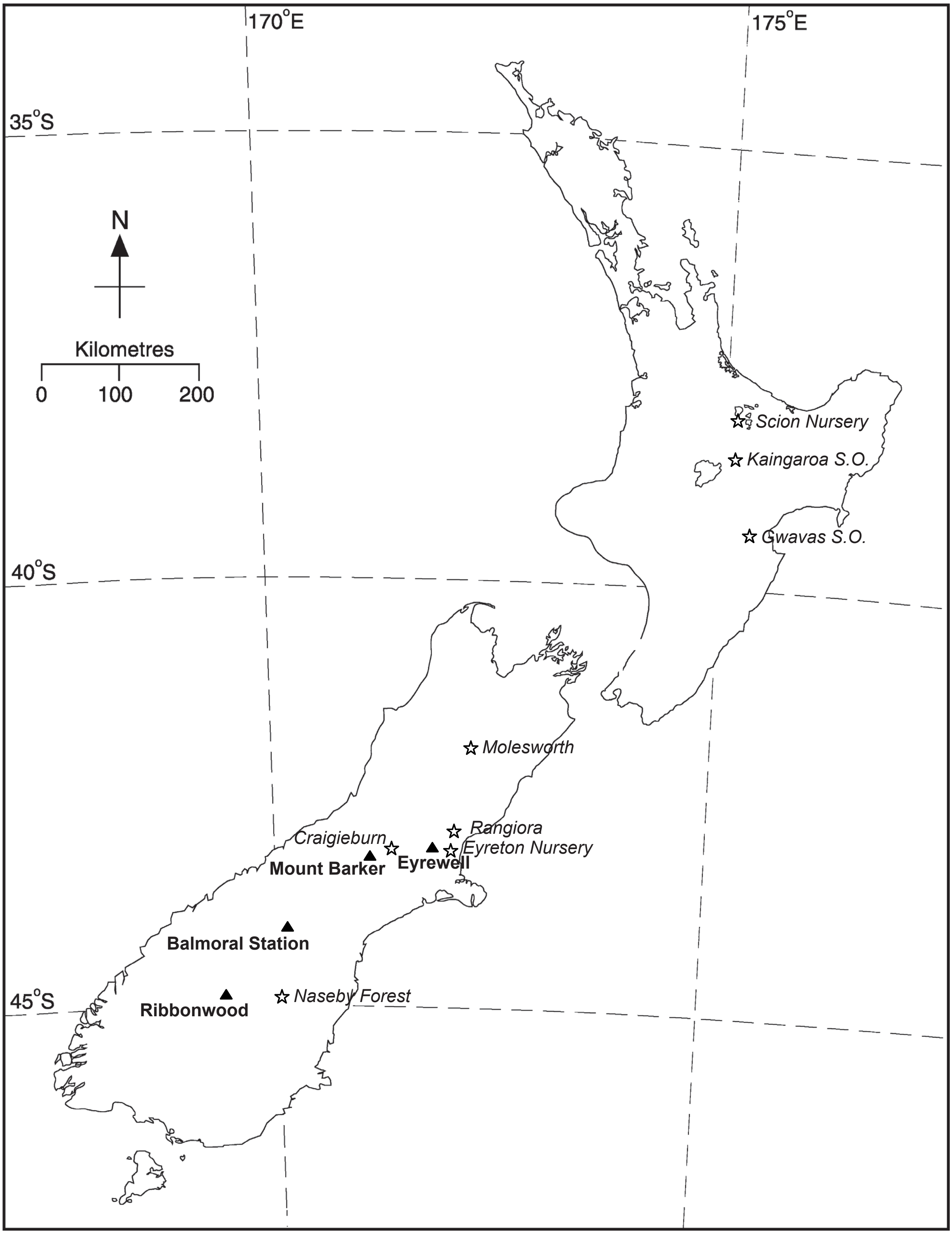

FIGURE 1: Locations of trials, nurseries and seed orchrds. **Current-trial sites** (▲); *other sites* (☆). Refer to Table 1 for details of climate.

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for *P. radiata* due to low temperatures, snowfall, and/or a range of lower rainfall areas (Molesworth 1000 m above sea level [a.s.l.], Craigieburn 850 – 880 m and Naseby 640 m; Table 1; Miller & Knowles, 1988). The hybrids were obtained from controlled pollinations producing two seedlots. The first seedlot was from a single *P. attenuata* female (seed parent), crossed with a polymix of a large number of *P. radiata* males (pollen). The second seedlot contained seed from two *P. radiata* females crossed with a polymix of four unrelated *P. attenuata* males from three different origins; Santa Cruz, California and the Coast Range. These seedlots were tested together with routine *P. radiata* from the Amberley Seed Orchard, near Christchurch (approximately 43º 06´ S, 172º 40´ E) and *P. muricata* D.Don ('blue form' collected from Hanmer Forest, approximately 42º 30´ S, 172º 50´ E). The design was based on three adjoining blocks at each site. The first block contained 96 trees of the two hybrid seedlots bulked, and each of the *P. radiata* and *P. muricata* seedlots, in a completely randomised design. The second plot contained 48 trees of the *P. radiata* × *P. attenuata* hybrids and the *P. muricata* seedlot in a split-plot design. The third block of 96 trees contained only the *P. radiata* × *P. attenuata* hybrid.

After 16 years, the hybrids in this second set of trials had grown better (larger DBH) than the pure species controls on two of the three sites, although their survival generally declined after 10 years (Table 2, Miller & Knowles, 1988). The hybrid trees showed considerable promise but more testing was needed to confirm their potential. Interestingly, the *P. muricata* tested had the best survival overall after 10 years (Table 2) but at no site had maximum height growth.

After five, seven and 16 years, the hybrids had grown higher than the pure *P. radiata* controls, although their survival was lower at the warmer site (Craigieburn; Table 2, Miller & Knowles, 1988). At age 16 years, the hybrids had the largest DBH at both sites measured but were clearly larger at the colder site (Molesworth). Survival of *P. radiata* was poor at the colder two sites (Molesworth and Naseby). The best survival across all sites was *P. muricata.* By age 9, all but one of the *P. radiata* had died at Naseby, and the trial was not actually measured after this point.

The hybrid trees showed considerable promise but more testing was needed to confirm their potential.

Current study

Further *P. attenuata* × *P. radiata* hybrids, produced from polycrossing using 15 selected *P. radiata* parents and 15 selected *P. attenuata* parents, were completed in 1994. A replicated trial with all seedlots was established on three South Island sites in 1998; Eyrewell Forest, Balmoral Station, and Ribbonwood Station, with surplus seedlings established in a further trial at Mount Barker. Eyrewell is a site climatically suited to *P. radiata* because of its mild temperatures, while Balmoral Station, Ribbonwood and Mountt

TABLE 2: Percentage survival and mean height (m) of the 1978 South Island trial after five, seven and 16 years of growth (Adapted from Miller & Knowles, 1988; J. T. Miller unpublished report, 1983; Burdon & Ledgard, unpublished data).

Taxon	Site					
	Craigieburn			Molesworth		Naseby
	Age 5	Age 7	Age 16	Age 5	Age 16	Age 5
			Survival (%)			
P. radiata × *P. attenuata*	47	40	35	50	37	37
(*P. attenuata* × *P. radiata*) × *P. radiata*	54	50	30	71	21	42
P. radiata	90	90	80	43	5	29
P. muricata	87	87	77	78	50	67
			Height (m)			
P. radiata × *P. attenuata*	1.47	3.19	10.8	1.55	9.4	0.9
(*P. attenuata* × *P. radiata*) × *P. radiata*	1.76	3.33	10 6	1.33	7.3	1.1
P. radiata	1.33	2.42	7.6	0.87	4.6	1.4
P. muricata	1.42	2.52	6.9	0.91	6.4	1.2
			DBH (cm)			
P. radiata × *P. attenuata*	-	-	25.0	-	19.8	
(*P. attenuata* × *P. radiata*) × *P. radiata*	-	-	25.6	-	15.3	
P. radiata	-	-	20.6	-	7.9	
P. muricata	-	-	16.9	-	13.9	

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Barker have harsher winters and are subject to regular winter snowfall. All sites were assessed for early growth performance and survival at approximately 4 and 8 years-of-age from planting, and snow damage at age 8. This study determines the early success of each of the different taxa and makes recommendations on the suitability of the hybrid for planted forests in the high-country of New Zealand's South Island.

Materials and methods

Open-pollinated cones were collected and seed extracted from 15 parent clones of *P. radiata* in Kaingaroa seed orchard, central North Island. Open-pollinated cones were also collected from 15 selected ortets of *P. attenuata*, growing in the 1961-planted provenance trial at Naseby Forest. Polycrossing of the same 15 *P. attenuata* clones, growing in a clonal archive at Rangiora, was completed in 1994 using a pollen mix from the same 15 clones of *P. radiata*.

These 45 seedlots were raised at the Scion nursery in Rotorua, in the North Island of New Zealand, along with three additional seedlots; a *P. radiata* × *P. attenuata* seedlot from the USA (also known as "KMX", ex Lee O. Hunt); a bulked seedlot of *P. radiata* × *P. radiata* var. *binata* parents from Guadalupe Island; and an open-pollinated Gwavas seed orchard Table 3) control of *P. radiata*. Seedlots of *P. attenuata* and *P. radiata* were grown as bare-root stock, for one year. Seedlots of *P. attenuata* × *P. radiata* were grown as bare-root stock for one-and-a-half years.

Trials were planted in 1998 and were all split-plot designs containing three blocks per replicate and 10 replicates. Each 'taxon' block contained two randomised non-contiguous individual-tree plots of each of the 15 progenies of each species or hybrid (*P. radiata, P. attenuata*, and *P. attenuata* × *P. radiata*; Table 3). Each plot also contained an USA.-made "KMX" hybrid (*P. attenuata x P. radiata),* a *P. radiata* × *P. radiata* var. *binata* hybrid - the "Guadalupe hybrid", and Gwavas-seed orchard stock, planted as controls (Table 3). The 10 replicates of each block were planted in a randomised complete block design at each of the three sites: Eyrewell Forest, Compartment 17, Canterbury (Table 1, 160 m a.s.l.), Balmoral Station, near Lake Tekapo (Table 1, 730 m asl) and at Ribbonwood Station, near Omarama (Table 1, 700 m asl). Spacing was 3 × 3 m, or approximately 1,111 stems per hectare. An additional demonstration site was established at Mount Barker (Table 1, 600 m asl) but results from this demonstration block are not reported here. Further site details, including rainfall and temperature are given in Table 1.

Due to the large climatic differences between the Scion nursery (Rotorua) and the planting sites in the high country, it was decided to lift all the plants, and

Table 3. Genetic material within the *Pinus radiata* × *P. attenuata* hybrid trial. All the open-pollinated *P. attenuata* families were collected from a progeny trial at Naseby. All the open-pollinated *P. radiata* families were collected from the Kaingaroa Seed Orchard.

Taxa	Seedlot Name	No. female parents	Seedlot type	Seed origin
P. attenuata	*P. attenuata*	6[1]	OP[2]	Siskiyou 5-Mix Everett Hill, California, USA.
		3	OP	Siskiyou 1-Mix West Branch, California, USA.
		4	OP	Josephine Org. 4-mix Oregon Caves, USA.
		2	OP	Siskiyou 6-mix Bartle, California, USA.
P. radiata	*P. radiata*	15[3]	OP	Kaingaroa Seed Orchard, New Zealand.
P. attenuata × *P. radiata*	KMX	unknown	OP	F_2 seed × F_1 orchard on Springs Farm, California, USA "KMX".
	P. attenuata × *P. radiata*	15	CP[2]	Same parents of *P. attenuata* and *P. radiata* used as given for pure species.
P. radiata × *P. radiata* var. *binata*[4]	Guadalupe hybrid	2	Polymix CP	Two selected New Zealand landrace crossed with 10-tree Guadalupe polymix.
P. radiata bulk	*P. radiata* bulk	-	OP	Gwavas Seed Orchard bulk 3/3/87/01, New Zealand.

[1]Pinus attenuata *seed was collected from the same parents as those represented in the pollen used for the hybrid crossing.*

[2]*OP = Open pollinated, CP = control pollinated.*

[3]*Control* P. radiata *seedlots were collected from the same parents as those represented in the pollen used for the hybrid crossing.*

[4] Pinus radiata *var.* binata *is from the Guadalupe provenance of* P. radiata *represented by pollen of 10 unrelated trees selected in New Zealand from provenance/progeny trials.*

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heel them in at a colder site, at Eyreton Nursary, near Rangiora, until required for planting. Unfortunately, when the plants were re-lifted, some individuals had suffered from decay on the stem, probably as a result of being in bundles. These individuals were discarded at planting and a *P. radiata* GF17 (97/576) (Anon. 2002) seedling ex Eyreton Nursery substituted. The specific replacements were: Eyrewell 1 individual; Balmoral Station 77; Ribbonwood 138 and; Mount Barker, eight.

During the winter of 2002, four years after planting, all four sites were assessed for early height growth and survival. Acceptability was also scored as 1 for a tree that would qualify as a crop tree in a thinning exercise and 0 for a tree deemed unacceptable on the basis of poor growth, stem straightness, forking or crown damage.

During the winter of 2006, eight years after planting, there was an exceptional snow fall and Balmoral Station, Ribbonwood and Eyrewell were assessed for height growth, survival, acceptability and snow damage. Snow damage was assessed on a scale of 0 to 5, representing the following classes; 0 = no damage, 1 = branches bent, 2 = branches broken, 3 = stem breakage 4 = stem bent, 5 = stem toppled.

Analysis

Univariate analyses of height growth, survival, acceptability and snow damage for the estimation of means and testing of significance of effects were undertaken using SAS (SAS Institute Inc., 1990).

For individual sites, least-squares means were estimated using model [1]

$$y_{ijkl} = \mu + R_i + T_j + F(T)_{jk} + R_i.T_j + R_i.\ F(T)_{jk} + \varepsilon_{ijkl} \quad [1]$$

Where y_{ijkl} is the individual-tree observation, μ is the overall mean, R_j is the effect of the *i*th replicate, T_j is the effect of species (taxon), either *P. radiata* or *P. radiata* × *P. attenuata*, $F(T)_{jk}$ is the effect of the k^{th} family nested within the j^{th} site, $R_i.\ F(T)_{jk}$ is the effect of the interaction between replicate and the family-within-taxon effect, and ε_{ijkl} is the residual (random). The replicate effect was considered fixed. All other effects were considered random. The *P. radiata* var. *binata* was classified as *P. radiata* and the 'KMX' hybrid seedlot as a *P. radiata* × *P. attenuata* hybrid.

Across-site analyses were undertaken for individual taxa using model [2]

$$y_{ijkl} = \mu + S_i + R(S)_{ij} + F_k + S_i.F_k + \varepsilon_{ijkl} \quad [2]$$

Where y_{ijkl} is the individual observation, μ is the overall mean, $R(S)_{ij}$ is the effect of the j^{th} replicate nested within the *i*th site, F_k is the effect of the k^{th} family, $S_i.F_k$ is the effect of the interaction between family and site, and ε_{ijkl} is the residual. All effects were considered random.

Analysis including provenance effects was under-taken using model [3]

$$y_{ijkl} = \mu + S_i + R(S)_{ij} + T_k + P_l + F(P)_{lk} + S_i.P_k + S_i.T_k + \varepsilon_{ijkl} \quad [3]$$

Where y_{ijkl} is the individual observation, μ is the overall mean, S_i is the effect of the i^{th} site, $R(S)_{ij}$ is the effect of the j^{th} replicate within the *i*th site, T_k is the effect of the k^{th} species (taxon), either *P. radiata*, *P. radiata* or *P. radiata* × *P. attenuata*, P_l is the effect of the l^{th} provenance, $F(P)_{lk}$ is the effect of the l^{th} family within the l^{th} provenance, $S_i.P_k$ is the effect of the interaction between the site and provenance effects, $S_i.T_k$ is the effect of the interaction between the replicate and the taxon effects, and ε_{ijkl} is the residual. All effects were considered random.

Results and Discussion

Analysis of variance

When data were analysed at individual sites, the taxa effect was significant for all traits at all sites ($0.01<p<0.05$ acceptability at Eyrewell, all other traits and sites $p<0.001$). The family-within-taxon effect was significant for all traits ($0.001<p<0.01$) except acceptability at Ribbonwood and Balmoral and snow damage and acceptability at Eyrewell. The replicate × taxa effect was significant for all traits at all sites ($0.01<p<0.05$) except for acceptability at age eight (Ribbonwood and Balmoral) and snow damage at Eyrewell. This effect being interpreted as a statistically significant block effect, indicating that the taxa in the tested environments are quite reactive to changes in micro-site variation.

When all three sites and taxa were analysed together, including provenance effects, the site × taxa was significant for all traits ($0.01<p<0.05$ acceptability, $p<0.001$ all other traits). The taxa effect was significant for height at both ages ($0.01<p<0.05$), but not for snow damage or acceptability. The provenance main effect was not significant for any trait, for any combination of sites. The replicate within site effect was significant for height growth ($p<0.001$) and acceptability ($0.001<p<0.01$) at age eight but not for snow damage. When the two colder sites (Balmoral and Ribbonwood) were analysed together, excluding Eyrewell, the site × taxa effect remained significant for all traits but snow damage ($0.001<p<0.01$). This is not surprising, as

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Eyrewell is not as subject to frost and snow as the other two sites. However, the site × taxa effect remained significant in most instances even for the two most similar sites, which means that the taxa are performing differently. The provenance effect was excluded from further analyses.

When individual taxa were analysed across all sites, site was significant for all traits and all taxa with the exception of *P. attenuata* snow damage (height $p<0.001$; acceptability $p<0.01$; snow damage *P. radiata* $p<0.001$, hybrids $0.01<p<0.05$). The family effect was significant for height only at age four and age eight for the hybrid ($p<0.001$), and was not significant for any other trait or taxon. This suggested that this material shows limited additive genetic variation across sites. It was interesting that the site × family effect was significant for more traits and taxa than the family effect alone: for example *P. attenuata* heights at ages four and eight ($p<0.001$), and acceptability at age eight ($0.01<p<0.05$ vs $p>0.05$); for *P. radiata* snow damage at age eight ($p<0.001$ vs $p>0.05$). The hybrids had no significant site × family effect for height or acceptability, but a significant effect for snow damage at age eight ($0.05>p>0.01$).

Means

When each taxon was considered separately across sites, *P. radiata* had the greatest average scores for height and acceptability, and the lowest snow damage score at Eyrewell (Table 4). Snow damage score was greatest at Ribbonwood, in contrast to Eyrewell, the mildest of the three sites. Both the hybrids and *P. attenuata* were taller at Ribbonwood at age four, then at Eyrewell at age eight (Table 4). Snow damage was the greatest at Ribbonwood for the hybrids but for the *P. attenuata,* there was no difference in snow damage between the sites and scores were very low for this taxon at all sites. *Pinus radiata* was the most damaged taxon at all sites. Balmoral Station, the coldest site, had the trees with the lowest height, for all taxa.

When the performance of taxa was compared within

TABLE 4: Demonstrating differences between sites for each taxon in the current study: Means at age four and eight for height (m) and for snow damage (1 – 5) and acceptability (0/1) at age eight for the different taxa *P. attenuata*, *P. attenuata* × *P. radiata* and *P. radiata* at each site.

	P. attenuata* x *P. radiata		***P. attenuata***		***P. radiata***	
Site/trait	**No. trees**	**Mean**	**No. trees**	**Mean**	**No. trees**	**Mean**
Height (m) at age four						
Ribbonwood	287	2.93 a	276	1.94 a	74	2.19 b
Balmoral Station	280	2.10 c[1]	272	1.44 c	97	1.72 c
Eyrewell	321	2.72 b	241	1.82 b	253	3.13 a
Least Significant Difference	0.09		0.08		0.17	
Height (m) at age eight						
Ribbonwood	285	6.93b	275	4.67b	57	5.24b
Balmoral Station	275	5.51c	271	3.86c	81	4.60c
Eyrewell	282	8.36a	233	5.31a	249	3.13 a
Least Significant Difference	0.20		0.16		0.52	
Snow damage score at age eight						
Ribbonwood	274	0.33a	275	0.05a	74	2.70a
Balmoral Station	284	0.19b	268	0.01a	81	1.52b
Eyrewell	281	0.09b	232	0.07a	255	0.82c
Least Significant Difference	0.12		0.07		0.38	
Acceptability score at age eight						
Ribbonwood	286	0.56b	275	0.33b	74	0.11b
Balmoral Station	273	0.55b	271	0.48a	81	0.11b
Eyrewell	283	0.75a	233	0.52a	255	0.63a
Least Significant Difference	0.09		0.10		0.14	

[1]*Means with different letters within a species are significantly different at $p\leq0.05$*

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sites (Table 5), the hybrid was the tallest at Balmoral and Ribbonwood, but *P. radiata* was the tallest at Eyrewell, the warmest site and this was consistent for both age four and age eight measurements (Table 5). The hybrid also had the most stems that were scored as acceptable at all three sites at age eight, although this was not significantly different from *P. attenuata* at Balmoral or from *P. radiata* at Eyrewell. Snow damage was consistently much lower in the hybrids and *P. attenuata* when compared with *P. radiata* at all sites (Table 5). At the two colder sites, the *P. attenuata* had significantly lower damage than the hybrids, but at Eyrewell, there was no significant difference between the two taxa. Comparing the survival of taxa within sites, percentage survival was greatest in *P. attenuata* at the two coldest sites at ages four and eight. At Eyrewell, *P. radiata* had the greatest survival at age four but, by age eight, this had switched to the hybrids.

Nursery and other limitations

Hybrids in the nursery had to be raised for one-and-a-half years versus one year for the pure species stock. The exact cause for this was not known, but it may have been due to the longer dormancy period of *P. attenuata* (C. B. Low personal communication, 4 December 2010). This has important implications for the cost of planting stock, as plants that require longer in the nursery cost more. Ideally, improvements in growing the hybrids in the nursery need to be made in order to reduce the growing time to one year and this may be as simple as ensuring longer stratification time for the hybrid seed.

The *P. radiata* means and ANOVA were generated including the 'GF17'-rated seedlot that was used to blank the trials (see Materials and Methods Section). To enable a direct comparison of genotype performance in genetics, it is important to utilise the same parents. However, for means and ANOVA, the GF17 seedlot represents a similar level of improvement and would be expected to be very similar to the *P. radiata* parents used in the trial. For these reasons, it seems realistic to include the seedlot in comparisons between taxa.

Conclusions

Pinus attenuata × *P. radiata* hybrids were produced and tested to determine their potential for plantation forestry in the New Zealand South Island high country. The hybrids were the tallest trees up to age eight on the two coldest sites tested (Ribbonwood and Balmoral Station). At the warmer site, Eyrewell, *P. radiata* was the tallest. *P. attenuata* was consistently the shortest taxon at all sites and ages. The hybrids have potential on the semi-continental sites in the South Island of New Zealand and may have application in similar environments in Australia and elsewhere, particularly where there is risk of snow damage.

In 1994, the estimated number of hectares in the South Island high country with potential for forestry

TABLE 5: Demonstrating differences between taxa at individual sites in the current study: Means for height (m) at age four and eight and for % acceptability (Accept.) and snow damage at age eight. The number of trees planted (planted), the number of trees surviving (N) at age four and eight and % survival for the taxa are also given for individual trials.

Taxa at each site	Planted	N. Age 4	Survival (%)	Height Age 4	N. Age 8	Survival (%)	Height (m)	Accept. (%)	Snow damage
Ribbonwood									
P. attenuata × *P. radiata*	335	287	86	2.93a[1]	285	85	6.78a	0.52a	0.41b
P. attenuata	299	276	92	1.94b	275	92	4.67c	0.33b	0.05a
P. radiata	330	74	22	2.19b	57	17	5.14b	0.11c	2.65c
Least Significant Difference				0.28			0.28	0.13	0.24
Balmoral Station									
P. attenuata × *P. radiata*	336	280	83	2.10a	275	82	5.43a	0.52a	0.21b
P. attenuata	299	272	91	1.44c	271	91	3.86c	0.48a	0.01a
P. radiata	314	97	31	1.72b	81	26	4.56b	0.08b	1.54c
Least Significant Difference				0.21			0.20	0.13	0.14
Eyrewell									
P. attenuata × *P. radiata*	300	284	95	2.72b	282	94	8.36b	0.75a	0.08b
P. attenuata	299	241	81	1.82c	233	78	5.31c	0.52b	0.07b
P. radiata	300	253	84	3.13a	249	83	10.0a	0.63ab	0.82a
Least Significant Difference				0.23			0.57	0.13	0.15

[1]*Means with different letters within a species are significantly different at* $p \leq 0.05$

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was around two million (Allen et al., 1994). Although there are concerns in the high country with the escape of wildlings, hybrid crosses such as *P. attenuata* × *P. radiata* offer real alternatives to some other pine species that are prone to spreading (e.g. *P. contorta* Douglas ex Loudon and *P. sylvestris* Linnaeus; Ledgard, 1999; Ledgard & Baker, 1985).

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