Eight year performance of provenances and New Zealand seed sources of Douglas-fir on higher altitude sites in the South Island

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NZ Douglas-fir Cooperative

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EIGHT YEAR PERFORMANCE OF PROVENANCES AND NEW ZEALAND SEED SOURCES OF DOUGLAS-FIR ON HIGHER ALTITUDE SITES IN THE SOUTH ISLAND

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SUMMARY

Open-pollinated seed was collected from 200 trees from coastal fog-belt populations in California and Oregon during 1993. 14 native populations in coastal California and Oregon, and five clonal seed orchards from the same region were sampled, and seed from seven NZ seed stands of Washington, Oregon and Californian origin were included as controls. Seed of native populations was bulked by population and planted with New Zealand seed orchard and seed stand seedlots in five seed source trials. Four of these trials on higher altitude and exposed "harder " sites and one on a valley bottom site, all in the South Island, were assessed at age 8-9 years from planting. At all sites, height, stem straightness, malformation and acceptability were assessed.

Growth was much slower at the highly-exposed Gowan Hills site (altitude 630m), which had lowest average straightness and malformation scores, whereas at Beaumont which was also very exposed but at an altitude of 430m, height growth was almost double but straightness and malformation scores were equally low. At the four "hard" trial sites (except Golden Downs) there were significant seedlot differences in height growth yet little difference in the growth performance of provenances from ca. 38°N latitude, northwards into Washington. The NZ seedlots of Fort Bragg, California origin (lat. 39° 15´) were growing at about the same rate as seedlots of southern Oregon and Washington origin. However at the lower, more sheltered Golden Downs site, the northern California provenances were clearly growing best, and the NZ seedlots from Fort Bragg, California were outgrowing the other NZ seedlots of Oregon and Washington origin by a large margin. At the four "harder" sites, the effects of environment on stem straightness, malformation and acceptability appear to have been so strong that they have largely obliterated any provenance differences at this age. In consequence, at higher altitude, exposed and snow-prone sites in Southland stock of Californian fog-belt origin has proven to be just as hardy as stock from southern Oregon or even Washington provenances.

Key words: Douglas-fir, Pseudotsuga menziesii, provenance, height, straightness, malformation, site, assessment

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INTRODUCTION

Coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [MIRB.] FRANCO) has been grown in plantations in New Zealand since about 1870 (Miller & Knowles 1994) and currently represents about five per cent of the NZ plantation area (NZ Forest industry Facts and Figures 2002/2003). However there has been a recent increase in planting of Douglas-fir, particularly on snow-prone, higher altitude sites in the South Island. There is thus considerable interest in whether the choice of Californian and southern Oregon provenances for planting on better quality, lower altitude sites, founded on the 1957 and 1959 provenance trial results, is supportable on these "harder" sites.

The first provenance trial of Douglas-fir was planted in 1957 from seed supplied by commercial seed companies (Sweet G.B., unpubl. data; Wilcox M.D., unpubl. data). The provenances in this first trial were collected from areas in Washington and Oregon where large timber industries were based around Douglas-fir. A second series of trials were planted in 1959 from seed collected from areas not represented in the first trial, particularly the coastal fog-belt of California and Oregon (G.B. Sweet, unpubl. data; M.D. Wilcox, unpubl. data). Further trials of local New Zealand seed sources and selected provenances were planted in 1971 and 1974 (C.J.A. Shelbourne, unpubl. data; M.D. Wilcox, unpubl. data).

A breeding programme was initiated in 1969 with plus-tree selection and collection of open-pollinated seed of these in Kaingaroa Forest stands of Washington origin, and progeny tests were planted in 1972. However, an assessment of the 1959 provenance trials at age 13 years (M.D. Wilcox, unpubl. data) showed clearly that Washington provenances grew up to 30 percent more slowly than provenances from the fog-belt on the coast of California. This news, as well as a general decline of industry interest in the species, effectively halted the breeding programme. However by 1987, the timber industry had started to show greater appreciation of Douglas-fir, and a new breeding programme was started by selecting trees from plots of the best-performing provenances growing in the 1957 and 1959 provenance trials (Shelbourne, in prep.). 185 trees were selected and scions from these were grafted to plant a clonal archive at Waikuku in Canterbury.

The need to broaden the genetic base of the breeding programme resulted in selection and open-pollinated seed collection from a further 200 trees from coastal fog-belt populations in California and Oregon during 1993 (Low *et al*. in press; Shelbourne, in prep.). This seed collection sampled 14 native populations in coastal California and Oregon, five clonal seed orchards from the same region. Seed from seven NZ seed stands of Washington, Oregon and Californian origin were included as controls. Open-pollinated progenies and controls were planted in progeny trials at three sites in North and South Islands. Seed was bulked of the same progenies from the native populations and planted as seed source trials on a further seven sites, all but one in the South Island, and an assessment of these trials at age eight years from planting is reported here.

MATERIAL AND METHODS

Seed collection

20 provenances (populations) were located in California and Oregon for seed collection and seed from three to 23 parent trees per stand was collected. However seedlots from only the 14 populations from California (Tables 1a & b, Fig. 1) were included in the seed source trials because the Oregon seedlots had too little seed in excess of that needed for the progeny trials. Parent trees were non-intensively selected at a minimum distance of 50 metres apart. Selection criteria were growth, bole straightness, crown form and health. The altitude of all populations was below 500 metres, and altitude for individual trees within a population often varied from 200 to 500 metres due to the hilly terrain. Up to four families from each of three seed orchards, owned by Weyerhaeuser in Oregon and Washington, were also planted individually in the seed source trials

In 1994 there was a good Douglas-fir seed crop in New Zealand and seed was collected from various New Zealand stands as "control" seedlots (Table 1). New Zealand seedlots 900, 901 and 903 are all derived from seed stands of Ft. Bragg origin (located at latitude 39°15´ on the Californian coast, just north of the Navarro river provenance). Seedlots 904 and 905, from Eyrewell and Mt. Thomas derive from an earlier seed stand at Ashley, probably of southern Oregon origin. Seedlot 906 from the Beaumont Tramway seed stand is of probable Washington origin but has neighbouring stands from the Ashley seed stand as possible pollen parents. Seedlot 902 is from Kaingaroa Cpt 1061, a second-generation stand of Washington origin.

Figure 1

Pacific Coast of North America, Douglas fir provenances

○ Provenance tested and selected for NZ Breeding Population

■ 1993 Seed Collection

Table 1a. Seedlots in 1996-planted seed source trials

Seed lot No.	Provenance/ Seed source	Number of parents	Latitude	Origin	Type of seed collection
808	US Los Padres N. F.	4	35° 49’	Monterey County, CA	Native forest
810	US Cascade Ranch	12	37° 08’	Santa Cruz county, CA	Native forest
809	US San Francisco W. R.	14	37° 27’	San Mateo county, CA	Native forest
812	US SP Taylor State Park	10	38° 02’	Marin county, CA	Native forest
811	US Pt Reyes	8	38° 04’	Marin county, CA	Native forest
813	US Russian river	6	38° 21’	Sonoma county, CA	Native forest
814	US Fort Ross	10	38° 25’	Sonoma county, CA	Native forest
815	US Gualala	9	38° 47’	Mendocino county, CA	Native forest
816	US Navarro river	11	39° 11’	Mendocino county, CA	Native forest
817	US Noyo river	18	39° 25’	Mendocino county, CA	Native forest
819	US Georgia Pacific	2	39° 25’	Mendocino county, CA	Seed Orchard
818	US Rockport	8	39° 47’	Mendocino county, CA	Native forest
907	US Louisiana Pacific	15	39°59´	Humboldt county, CA	Seed Orchard
825	US Simpsons Timber	>10	40-41°	Humboldt / Del Norte, CA	Seed Orchard
900	NZ Rotoehu 55	>50	(39°15´)	56/654 Ft Bragg, CA	Seed stand
901	NZ Kaingaroa 1132	>50	(39°15´)	R78/34 ex Rotoehu cpt.55	Seed stand
903	NZ Golden Downs 115	>50	(39°15´)	56/654 Ft Bragg, CA	Seed stand
904	NZ Eyrewell Main Race		(ca.43°)	Ashley (ex Oregon)	Seed stand
905	NZ Mount Thomas		(ca.43°)	Ashley (ex Oregon)	Seed stand
906	NZ Beaumont, Tramway		(ca.48°)	Washington	Seed stand
902	NZ Kaingaroa 1061		(ca.48°)	R63/701, R64/734 (Kaingaroa, ex Washington)	Road edge

Table 1b. Weyerhaeuser orchard progeny seedlots in seed source trials

Seedlot No.	Progeny (OP family, ex orchard)	Latitude	Location	Type of seed collection
122	US Weyerhaeuser #1	43° 25’	Coos Bay, OR	Seed Orchard
222	US Weyerhaeuser #2 („)	43° 25’	Coos Bay, OR	Seed Orchard
322	US Weyerhaeuser #3 („)	43° 25’	Coos Bay, OR	Seed Orchard
422	US Weyerhaeuser #4 („)	43° 25’	Coos Bay, OR	Seed Orchard
123	US Weyerhaeuser #1 („)	46° 30’	Long View, WA	Seed Orchard
223	US Weyerhaeuser #2 („)	46° 30’	Long View, WA	Seed Orchard
323	US Weyerhaeuser #3 („)	46° 30’	Long View, WA	Seed Orchard
423	US Weyerhaeuser #4 („)	46° 30’	Long View, WA	Seed Orchard
124	US Weyerhaeuser #1 („)	48° 05’	Twin Harbours, WA	Seed Orchard
224	US Weyerhaeuser #2 („)	48° 05’	Twin Harbours, WA	Seed Orchard
324	US Weyerhaeuser #3 („)	48° 05’	Twin Harbours, WA	Seed Orchard
424	US Weyerhaeuser #4 („)	48° 05’	Twin Harbours, WA	Seed Orchard

Nursery sowing and raising of plants

Progeny seedlots from the Californian native populations (of which there was sufficient seed for both progeny trials and provenance trials) were bulked by population (Table 1). The seed was stratified for two weeks and sown in early December 1994, to provide one-and-a-half year-old bare-rooted plants for planting in winter (August) 1996. The nursery layout of the families was in randomised complete blocks with three replicates, which helped minimise effects of growth differences along nursery beds.

Field sites, layout and planting

The trial series was planted on seven sites (Table 2, Fig. 1) but rabbits destroyed most trees on the Ribbonwood site within days of their being planted. This left five sites in the South Island, which ranged from a valley-bottom "normal" Douglas-fir site at Golden Downs, altitude 370 m to other higher altitude sites at Hanmer and in Otago and Southland that were either very frost-prone or hilltop and exposed to wind damage, some more than others. The North Island site, Tauhara, has been repeatedly frosted, has serious weed problems and was not assessed.

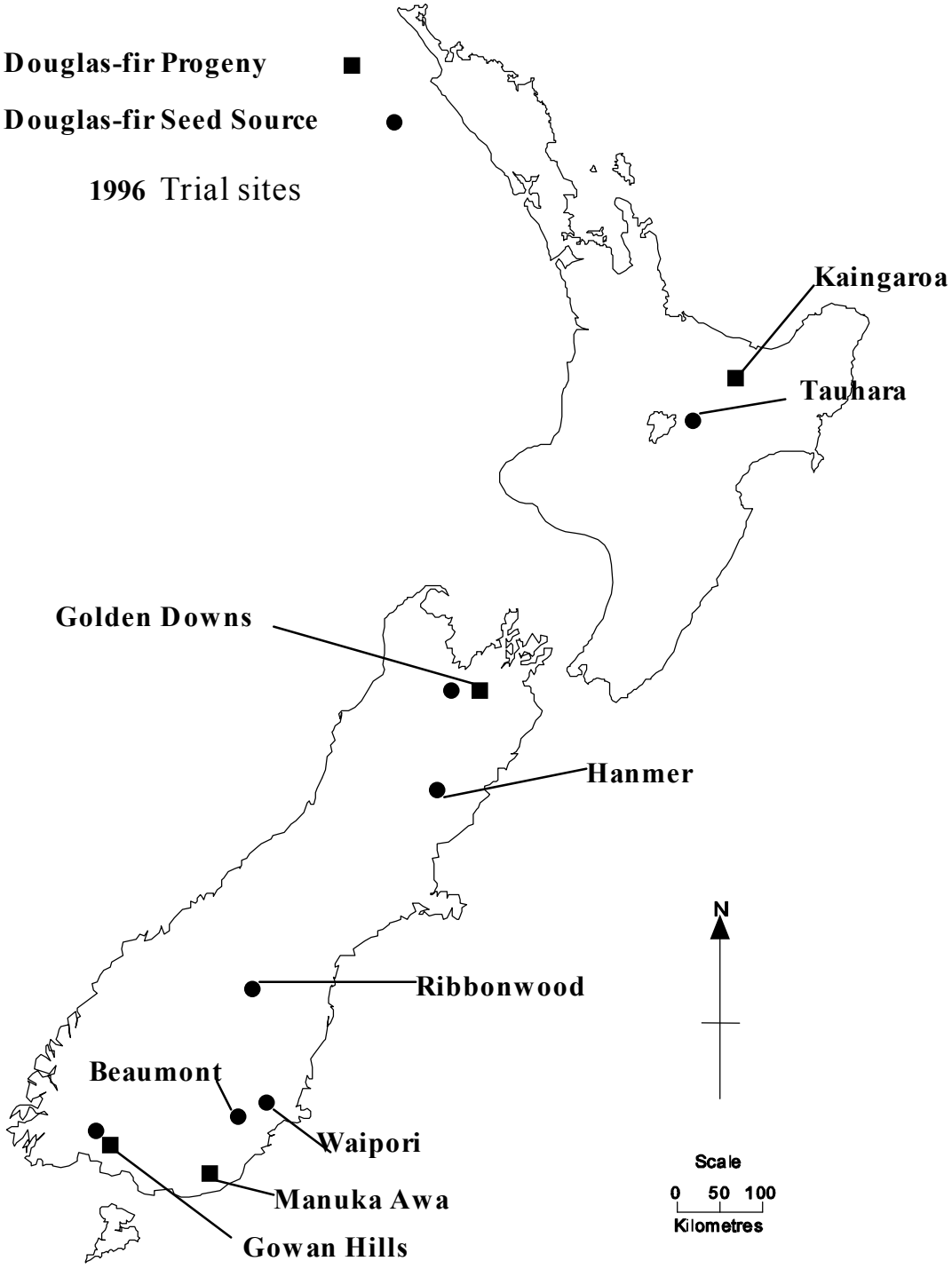

Figure 2. Locations of 1996 Douglas-fir trials

Table 2. Seed source trial site descriptions

Forest	Cpt	Latitude	Altitude (metres)	Soil type	Previous use	Remarks
Golden Downs	247	41°33′	370	granitic	*P. radiata* cutover	Valley bottom, Browsed by possums in first year, weeds were controlled by spray.
Tauhara	521	38°35′	500	pumice	*P. radiata* cutover	Mid-slope, browsed by rabbits, vigorous buddleia, uneven growth
Hanmer	13	42°32′	500	loess over gravel	*P. nigra* cutover	Mid slope, browsed by hares and rabbits, frosted, heavy broom in places
Waipori	8/15	45°50	300	loess over gravel	*P. ponderosa* / Douglas-fir cutover	Near ridgetop, spot mounded, but still frosted and browsed. Some Douglas-fir regeneration heavy in patches
Ribbonwood		44°24′	600	loess over gravel	farmland	Mid slope. 90% of trees eaten by rabbits within a week of planting. Site abandoned.
Gowan Hills	746	45°54′	630	loess over gravel	farmland	Hilltop. Planted into ripped lines. Slow start but good survival amongst tall tussocks
Beaumont	27	46°03′	430	loess over gravel	cutover	Top of forest. Root-raked and spot mounded. Good survival, some blackberry and gorse patches, mainly browntop grass

The randomised complete block trial design utilised 10 replicates of 5-tree row plots at each site at a spacing of 3×3m. Two additional replicates of 49-tree blocks were planted at each site for establishing permanent sample plots for volume growth estimation. These were of seedlot 900 (Rotoehu seed stand of Ft. Bragg, California origin), 904 (Eyrewell seed stand, ex Ashley, probably of south Oregon origin), and 906 (Beaumont, Tramway of Washington origin). The Beaumont and Gowan Hills sites had only six replicates due to a shortage of plants.

The trees grew much more slowly and encountered more weed and browsing problems on these hard sites than the same material in the 1996 progeny trial. Four of the remaining six sites suffered problems after establishment (see Table 2).

The progeny trials (Low *et al*. in press) were planted at three "normal" Douglas-fir sites in August 1996 (Table 3, Fig. 2). The sites are located at Kaingaroa Forest in the North Island, and at Golden Downs and Gowan Hills Forests in the South Island. The progeny trial sites were better-than-average sites in each area, with adequate rainfall (1200mm to 1900mm) occurring throughout the year, a mild climate and good growth potential. Establishment was excellent at all progeny trial sites and effective weed control resulted in good early growth.

Table 3. Progeny trial site descriptions

Site	Altitude (metres)	Latitude	Soil type	Owner	Previous use	Land preparation	Rainfall (mm)	Mean monthly temperature, Celsius
Kaingaroa Cpt 1322	300	38°17´	Tarawera scoria over Taupo ash	Kaingaroa Timberlands Limited	*Pinus radiata* plantation	Herbicide application to kill weeds	1855	6.6° July to 17.6° February
Golden Downs Cpt 114	350	41°33´	Moutere gravel	Weyerhaeuser	Douglas-fir plantation	Herbicide application, fertilised at age 3	1304	6.1° July to 17.1° February
Gowan Hills Cpt 740	300	45°54´	Pourakino yellow-brown earth	Ernslaw One Ltd.	sheep pasture	Deep ripped, mounded, herbicide application	987	4.3° July to 14.3° January

Assessment

Assessment of Golden Downs, Hanmer, Waipori, Gowan Hills and Beaumont seed source trials was made at age 8 years. Assessment traits height, diameter at breast height (DBH), bole straightness, malformation, needle retention and acceptability were measured/scored as shown in Table 4. Diameters were only measured at Hanmer and Waipori, as it was difficult to reach through the dense, live branches and thread the tape around the stem. Needle retention was assessed at Golden Downs only, as needlecast was clearly evident and relatively easy to score.

Table 4. Assessment traits

Trait	Units	Description
Height	Dm	by height pole
Diameter	Mm	by tape (2 sites only)
Straightness	1-9	Score 1-9 (1-4 unacceptably sinuous, 6-9 acceptably straight
Malformation	1-9	Score 1 = repeated forking to 9= no forks or ramicorns
Needle retention	1-8	6 months of needles score 1 point to a maximum of 8. (only assessed at Golden Downs)
Acceptability	0 or 1	1 = acceptable for growth, form and health; 0 = unacceptable

The progeny trials were assessed earlier at age four years for a variety of traits of which tree height, bole straightness score (1-9 scale), needle retention (1-6 score, at Kaingaroa only in late November and early December) were in common with the traits measured in the seed source trials (see Low *et al*. in press). Forks were also recorded by presence or absence for each of three years growth, so the score for forks ranged from 0 to 3.

Analysis

The field design was a randomised complete block design. The equation for the model of analysis of variance for such a design on a single site was as follows:

$$Y_{ij} = \mu + R_i + P_j + R_i : P_j + E_{ij}$$

Where :

Y_{ij} = the observation on a tree of the jth provenance in the ith replicate

μ = the overall mean

R_i = the effect of the ith replicate

P_j = the effect of the jth provenance

$R_i : P_j$ = the interaction effect of the ith replicate with the jth provenance

E_{ij} = the random error associated with each tree of the jth provenance in the ith replicate

The equation for the analysis of variance model on several sites has more effects than the single site model as it contains a term for sites and a term for the interaction of provenance with site:

$$Y_{ijk} = \mu + S_i + R_j : S_i + P_k + P_k * S_i + E_{ijk}$$

Where :

Y_{ijk} = the observation on the tree of the kth provenance in the jth replicate of the ith site

μ = the overall mean

S_i = the effect of the ith Site

$R_j : S_i$ = the effect of the jth replicate within the ith site

P_k = the effect of the kth provenance

$P_k * S_i$ = the interaction effect of the kth provenance with the ith site

E_{ijk} = the random error associated with each tree of the kth provenance in the jth replicate of the ith site

The first analysis of this set of trials examined the data from each site separately. Analysis of variance was carried out by PROC GLM of the SAS® statistical package (SAS Institute inc. 1989) and provenance means were compared using the least significant difference. The terms of the analysis model were replicates, provenances, a replicate by provenance interaction and error. Replicate and replicate by provenance interaction were treated as random effects and provenance was treated as a fixed effect.

An overall analysis of variance for all five sites was also carried out. This analysis contained the same terms as the single site models, but also included site and its interaction with provenances. Site, replicates within site, provenance and interaction terms were treated as random effects.

Seedlot means were estimated using PROC MEANS of the SAS® software package (SAS Institute inc. 1990) at each site. Pearson correlation coefficients (r values) were estimated by PROC CORR of the SAS® software package.

RESULTS AND DISCUSSION

Seedlot means for height, straightness, malformation and acceptability scores at age eight years at each of the five seed source trials are given in Tables 5, 6, 7 & 8. For each within-site analysis, the least significant difference between means, site mean, standard deviation and F ratio for the seedlots term in the ANOVA are shown at the bottom of the page. Least squares means across sites are shown in Table 9. Provenance mean height, straightness and forking % at age four years in the associated progeny trials at three additional sites (Low *et al*. in press) are shown for comparison. Native population and seed orchard seedlots, all from coastal populations, are shown in order of increasing latitude of origin. Seedlots 22, 23 and 24 represent means of from one to four open-pollinated families from Weyerhaeuser seed orchards at Coos Bay, Long View and Twin Harbours respectively.

Table 5. Height age 8 years in seed source trials, compared with height age 4 years in progeny trials

Seed lot	Provenance	Latitude	Seed source Trials: Height age 8 years					Progeny Trials: Height age 4 years		
			Gowan Hills	Beau-mont	Waipori	Hanmer	Golden Downs	Gowan Hills	Golden Downs	Kainga roa
808	US Los Padres N. F.	35° 49’	14.6	38	38	40	35	17.2	14.2	20.7
810	US Cascade Ranch	37° 08’	19.0	43	39	49	43	22.1	19.6	25.7
809	US San Francisco W. R.	37° 27’	18.0	45	42	45	44	20.3	17.4	22.3
812	US SP Taylor State Park	38° 02’	20.3	45	41	46	37	21.3	19.9	24.1
811	US Pt Reyes	38° 04’	19.5	45	41	47	45	21.8	18.4	23.9
813	US Russian river	38° 21’	21.4	45	43	45	42	22.2	21.1	25.6
814	US Fort Ross	38° 25’	17.6	42	42	48	49	22.5	22.7	29.6
815	US Gualala	38° 47’	17.7	44	40		45	22.0	22.4	26.4
816	US Navarro river	39° 11’	18.3	47	45	51	53	23.6	23.2	28.2
817	US Noyo river	39° 25’	19.5	42	45	50	44	21.0	21.5	25.6
819	US Georgia Pacific	39° 25’	19.2	44	42	50	51			
818	US Rockport	39° 47’	19.5	42	42	46	51	21.5	21.7	24.6
907	US Louisiana Pacific SO	39°59´	22.2	46	44	54	47	22.2	19.4	26.8
825	US Simpsons	40-41°	24.3	45	43	49	45			
22	Coos Bay	43°25´	22.8	48	46	51	47		21.4	26.5(1)
23	Long View	46°30´	23.7	43	45	48	46		16.0	21.8(3)
24	Twin Harbours	48°05´	22.1		47	47	48		16.3	21.9(2)
900	NZ Rotoehu 55	(39°15´)	22.7	47	46	46	57	24.3	23.8	29.8
901	NZ Kaingaroa 1132	(39°15´)	24.1	46	46	52	55	22.5	23.6	29.2
903	NZ Golden Downs 115	(39°15´)	23.9	44	44	49	53	21.9	22.3	28.4
904	NZ Eyrewell Main Race	(ca.43°)	24.1	47	45	47	43	23.7	18.5	22.9
905	NZ Mount Thomas	(ca.43°)	25.8	45	48	48	39	21.6	19.0	24.0
906	NZ Beaumont, Tramway	(ca.48°)	23.5	44	44	51	46	21.0	20.7	24.6
902	NZ Kaingaroa 1061	(ca.48°)	23.7	43	47	49	46	21.8	17.4	24.8
Least Significant Difference			5.7	5.7	6.5	10.9	16.3	1.59	2.04	1.96
Mean			21.6	44.6	44.2	45.5	46.4	21.5	19.7	24.9
Standard Deviation			2.7	2.4	2.6	4.0	4.8	1.35	2.67	2.30
F ratio for seedlots (within sites)[1]			5.32***	2.84***	2.20***	1.79*	2.71***			

[1] * p = 0.05, ** p = 0.01, *** p = 0.001

Table 6. Straightness age 8 years in seed source trials, compared with straightness age 4 years in progeny trials

Seed lot	Provenance	Latitude	Seed source Trials: Straightness age 8 years					Progeny Trials: Straightness age 4 years		
			Gowan Hills	Beau-mont	Waipori	Hanmer	Golden Downs	Gowan Hills	Golden Downs	Kainga roa
808	US Los Padres N. F.	35° 49’	6.77	6.18	6.96	7.38	8.67	6.84		7.50
810	US Cascade Ranch	37° 08’	5.45	5.07	6.39	7.56	8.81	6.66		6.82
809	US San Francisco W. R.	37° 27’	5.45	6.14	6.33	7.47	8.26	6.84		7.13
812	US SP Taylor State Park	38° 02’	5.62	5.53	6.21	7.11	8.48	6.73		6.95
811	US Pt Reyes	38° 04’	5.64	5.43	6.33	6.90	8.40	6.69		6.91
813	US Russian river	38° 21’	5.68	5.79	6.93	6.79	8.37	6.56		6.75
814	US Fort Ross	38° 25’	5.70	5.21	5.12	6.47	8.00	6.31		6.22
815	US Gualala	38° 47’	5.09	4.80	5.31		8.25	6.29		6.70
816	US Navarro river	39° 11’	5.67	5.15	5.91	6.32	8.48	6.55		6.84
817	US Noyo river	39° 25’	5.95	5.26	5.33	6.83	8.12	6.64		7.19
819	US Georgia Pacific	39° 25’	5.73	5.64	6.03	6.82	8.57			
818	US Rockport	39° 47’	5.48	5.93	5.81	6.95	8.45	6.49		7.12
907	US Louisiana Pacific SO	39°59´	5.89	5.33	5.91	6.59	8.42	6.74		7.21
825	US Simpsons	40-41°	5.42	5.96	5.90	7.29	8.42			
22	Coos Bay	43°25´	5.50	5.28	6.14	6.07	8.40			7.30(1)
23	Long View	46°30´	5.35	5.61	5.88	6.61	8.49			7.25
24	Twin Harbours	48°05´	5.68	5.07(1)	5.80	6.67	8.17			7.62(2)
900	NZ Rotoehu 55	(39°15´)	5.44	4.48	5.58	6.28	8.29	6.48		6.94
901	NZ Kaingaroa 1132	(39°15´)	4.96	5.23	5.46	6.88	8.44	6.77		7.08
903	NZ Golden Downs 115	(39°15´)	5.54	5.37	5.63	6.78	8.42	6.48		6.91
904	NZ Eyrewell Main Race	(ca.43°)	6.00	5.55	6.46	6.62	8.47	6.57		7.29
905	NZ Mount Thomas	(ca.43°)	4.93	5.56	6.42	6.68	8.58	6.50		7.22
906	NZ Beaumont, Tramway	(ca.48°)	5.39	5.68	6.38	7.22	8.32	6.38		7.54
902	NZ Kaingaroa 1061	(ca.48°)	4.62	5.72	6.13	6.63	8.26	6.71		7.54
Least Significant Difference			1.60	1.66	1.65	1.59	0.93	0.35		0.49
Mean			5.53	5.45	6.00	6.76	8.39	6.60		7.05
Std. Deviation			0.41	0.46	0.43	0.41	0.18	0.16		0.35
F ratios for seedlots (within sites)			1.43	1.74*	1.19	1.12	1.10			

Table 7. Malformation age 8 years in seed source trials, compared with forking age 4 years in progeny trials

Seed lot	Provenance	Latitude	Seed source Trials: Malformation age 8 years					Progeny Trials: Forking age 4 years		
			Gowan Hills	Beau-mont	Waipori	Hanmer	Golden Downs	Gowan Hills	Golden Downs	Kainga roa
808	US Los Padres N. F.	35° 49’	5.85	6.43	6.83	8.38	8.26	0.62	1.07	0.57
810	US Cascade Ranch	37° 08’	6.10	6.40	6.82	8.28	8.88	0.42	0.80	0.42
809	US San Francisco W. R.	37° 27’	6.00	7.07	6.82	8.65	8.42	0.43	0.91	0.38
812	US SP Taylor State Park	38° 02’	5.86	7.03	7.00	8.06	8.85	0.46	0.94	0.52
811	US Pt Reyes	38° 04’	5.73	6.57	6.93	8.30	8.66	0.45	0.97	0.55
813	US Russian river	38° 21’	5.91	5.97	6.52	8.20	8.33	0.51	0.90	0.51
814	US Fort Ross	38° 25’	5.85	5.89	7.00	8.00	8.46	0.43	0.69	0.53
815	US Gualala	38° 47’	5.91	6.27	6.69		8.97	0.39	0.73	0.42
816	US Navarro river	39° 11’	6.06	6.52	6.71	8.58	8.91	0.39	0.69	0.51
817	US Noyo river	39° 25’	6.26	5.85	7.33	8.67	8.42	0.39	0.67	0.50
819	US Georgia Pacific	39° 25’	5.41	5.82	6.81	8.27	8.70			
818	US Rockport	39° 47’	6.10	6.60	7.54	8.33	8.79	0.47	0.79	0.55
907	US Louisiana Pacific SO	39°59´	6.00	6.67	6.69	8.59	8.72	0.41	0.48	0.63
825	US Simpsons	40-41°	6.15	6.75	6.83	8.50	8.82			
22	Coos Bay	43°25´	5.96	6.37	6.79	8.22	8.76		0.76	0.44(1)
23	Long View	46°30´	6.06	6.64	6.67	8.52	8.82		0.73	0.52
24	Twin Harbours	48°05´	5.95	5.27(1)	7.04	8.37	8.81		0.77	0.62(2)
900	NZ Rotoehu 55	(39°15´)	5.80	5.90	6.64	8.00	8.81	0.48	0.68	0.41
901	NZ Kaingaroa 1132	(39°15´)	5.64	5.87	6.83	8.54	8.72	0.35	0.67	0.44
903	NZ Golden Downs 115	(39°15´)	6.12	6.20	6.44	7.83	8.65	0.56	0.57	0.57
904	NZ Eyrewell Main Race	(ca.43°)	6.07	7.21	7.32	8.57	8.91	0.32	1.08	0.67
905	NZ Mount Thomas	(ca.43°)	5.90	7.41	6.42	8.32	8.85	0.46	0.75	0.30
906	NZ Beaumont, Tramway	(ca.48°)	5.68	6.46	7.10	8.43	8.65	0.50	0.46	0.38
902	NZ Kaingaroa 1061	(ca.48°)	5.81	5.72	7.40	8.00	8.65	0.43	0.52	0.31
Least Significant Difference			1.59	1.79	1.91	1.53	0.73	0.21	0.28	0.24
Mean			5.94	6.39	6.87	8.36	8.73	0.40	0.76	0.49
Standard Deviation			0.21	0.51	0.33	0.27	0.18	0.10	0.16	0.07
F ratios for seedlots (within site)			0.45	2.38***	0.84	0.94	1.86**			

Table 8. Acceptability (age 8 years) and needle retention (age 9 years Golden Downs).

Seedlot	Provenance	Latitude	Gowan Hills	Beau-mont	Waipori	Hanmer	Golden Downs	Golden Downs needle retention
808	US Los Padres N. F.	35° 49’	0.22	0.46	0.48	0.53	0.48	2.15
810	US Cascade Ranch	37° 08’	0.27	0.47	0.64	0.62	0.73	2.65
809	US San Francisco W. R.	37° 27’	0.30	0.76	0.58	0.65	0.74	1.97
812	US SP Taylor State Park	38° 02’	0.36	0.63	0.57	0.67	0.44	2.03
811	US Pt Reyes	38° 04’	0.26	0.61	0.59	0.86	0.83	3.23
813	US Russian river	38° 21’	0.56	0.62	0.65	0.69	0.73	2.50
814	US Fort Ross	38° 25’	0.31	0.50	0.48	0.53	0.74	3.31
815	US Gualala	38° 47’	0.11	0.43	0.52		0.79	2.78
816	US Navarro river	39° 11’	0.30	0.44	0.59	0.68	0.94	3.52
817	US Noyo river	39° 25’	0.40	0.33	0.56	0.65	0.68	2.31
819	US Georgia Pacific	39° 25’	0.19	0.46	0.52	0.70	0.84	3.27
818	US Rockport	39° 47’	0.31	0.53	0.55	0.77	0.76	3.15
907	US Louisiana Pacific SO	39°59´	0.34	0.43	0.49	0.88	0.75	3.47
825	US Simpsons	40-41°	0.39	0.61	0.55	0.71	0.77	3.27
22	Coos Bay	43°25´	0.37	0.45	0.55	0.61	0.77	3.71
23	Long View	46°30´	0.35	0.55	0.48	0.73	0.82	3.75
24	Twin Harbours	48°05´	0.38	0.37	0.55	0.69	o.82	3.68
900	NZ Rotoehu 55	(39°15´)	0.29	0.24	0.52	0.55	0.97	3.81
901	NZ Kaingaroa 1132	(39°15´)	0.46	0.40	0.49	0.85	0.86	4.03
903	NZ Golden Downs 115	(39°15´)	0.39	0.53	0.45	0.57	0.97	3.06
904	NZ Eyrewell Main Race	(ca.43°)	0.50	0.62	0.62	0.59	0.77	3.82
905	NZ Mount Thomas	(ca.43°)	0.30	0.67	0.58	0.70	0.57	3.88
906	NZ Beaumont, Tramway	(ca.48°)	0.38	0.43	0.55	0.85	0.72	3.97
902	NZ Kaingaroa 1061	(ca.48°)	0.21	0.45	0.60	0.63	0.77	4.32
Least Significant Difference			0.48	0.48	0.44	0.54	0.44	1.33
Mean			0.32	0.48	0.36	0.51	0.77	
Standard Deviation			0.09	0.11	0.06	0.11	0.12	
F ratio for seedlots (within site)			0.93	1.30	0.68	0.99	2.15***	6.57***

Table 9. Seed source trials; least squares means across sites for height, acceptability, straightness and malformation age 8 years

Seed-lot	Provenance	Latitude	Height	Std. Error	Accept-ability	Std. error	Straight ness	Std error	Malfor-mation	Std. error
808	US Los Padres N. F.	35° 49’	32.24	0.87	0.44	0.04	7.16	0.15	7.14	0.15
810	US Cascade Ranch	37° 08’	37.65	0.82	0.55	0.04	6.59	0.13	7.35	0.14
809	US San Francisco W. R.	37° 27’	37.55	0.79	0.60	0.04	6.66	0.13	7.33	0.13
811	US Pt Reyes	38° 04’	39.02	0.81	0.62	0.04	6.50	0.13	7.21	0.13
812	US SP Taylor State Park	38° 02’	37.03	0.80	0.52	0.04	6.55	0.13	7.43	0.13
813	US Russian river	38° 21’	39.35	0.82	0.64	0.04	6.68	0.13	6.96	0.13
814	US Fort Ross	38° 25’	39.34	0.87	0.52	0.04	6.05	0.14	7.05	0.14
815	US Gualala	38° 47’	37.94	0.89	0.49	0.04	5.92	0.14	7.23	0.15
816	US Navarro river	39° 11’	42.46	0.82	0.61	0.04	6.33	0.13	7.36	0.14
817	US Noyo river	39° 25’	38.63	0.85	0.52	0.04	6.18	0.14	7.28	0.14
819	US Georgia Pacific	39° 25’	41.29	0.82	0.55	0.04	6.55	0.13	7.04	0.13
818	US Rockport	39° 47’	40.32	0.82	0.58	0.04	6.49	0.13	7.49	0.14
907	US Louisiana Pacific SO	39° 59´	42.00	0.80	0.56	0.04	6.42	0.13	7.31	0.13
825	US Simpsons	40-41°	40.20	0.79	0.60	0.04	6.58	0.13	7.40	0.13
22	Coos Bay	43° 25´	42.27	0.85	0.56	0.04	6.31	0.14	7.25	0.14
23	Long View	46° 30´	42.28	0.81	0.58	0.04	6.22	0.13	6.97	0.13
24	Twin Harbours	48° 05´	41.05	0.83	0.58	0.04	6.36	0.13	7.30	0.14
900	NZ Rotoehu 55	(39° 15´)	43.83	0.82	0.51	0.04	5.99	0.13	7.04	0.13
901	NZ Kaingaroa 1132	(39° 15´)	44.65	0.76	0.61	0.04	6.18	0.12	7.15	0.12
903	NZ Golden Downs 115	(39° 15´)	42.27	0.81	0.59	0.04	6.32	0.13	7.10	0.13
904	NZ Eyrewell Main Race	(ca.43°)	40.73	0.79	0.62	0.04	6.60	0.13	7.64	0.13
905	NZ Mount Thomas	(ca.43°)	40.20	0.82	0.55	0.04	6.42	0.13	7.31	0.13
906	NZ Beaumont, Tramway	(ca.48°)	40.20	0.82	0.55	0.04	6.42	0.13	7.31	0.13
902	NZ Kaingaroa 1061	(ca.48°)	40.97	0.82	0.53	0.04	6.25	0.13	7.15	0.13
Mean			40.51	0.83	0.56	0.04	6.39	0.13	7.26	0.14

Site effects
The effects of site on height growth were far greater than the effects of provenance in these trials. In particular the trees grew much slower at the 630m altitude site at Gowan Hills, the highest in altitude and very exposed. Mean height of 2.2m was about half those at the other sites. In the progeny test at a lower altitude, 300m, in the same forest, heights at age four years were only a little less than on a favourable 300m site in Kaingaroa Forest in the central North Island. Heights at the other seed source trials averaged 4.4 to 4.9 m, though altitudes ranged from 300-500m. Various countervailing factors, including altitude, temperature, exposure, moisture, fertility and browsing by possums have resulted in quite similar height growth at these sites. Photos (Figs. 2, 3 & 4) show typical tree form induced by sheltered, moderately exposed and very exposed sites.

Figure 3. Excellent stem straightness on a sheltered site, Golden Downs forest

Figure 4. Sinuosity induced by a moderately exposed site, Beaumont forest

Figure 5. Slow growth with stem sinuosity and leader breakage on a very exposed site, Gowan Hills

Stem straightness was much the best at Golden Downs on a sheltered valley bottom site, with a mean score of 8.4. Straightness was also good at Hanmer but worst at Beaumont (5.5) and Gowan Hills (5.5), both exposed sites. Malformation scores followed the same pattern, with most multi-leaders at Gowan Hills (5.9) and least at Hanmer and Golden Downs (8.4 & 8.7). Average acceptability (for growth, stem form and health) varied widely at the different sites from 32% at Gowan Hills, 36% at Waipori, 48% at Beaumont, 51% at Hanmer to 77% at Golden Downs. Clearly the sheltered site at Golden Downs was a much better one for tree form of Douglas-fir than the others, though height growth was no better than at Beaumont, Waipori and Hanmer.

Survival was affected by animal browsing, with the Gowan Hills and Beaumont sites best at 93 and 96%, Golden Downs at 78%, Hanmer and Waipori at 66%. The Los Padres seedlot was the worst affected seedlot at 44 and 51% at the most heavily browsed sites, with Santa Cruz seedlots also affected more than most. Other Californian seedlots fared as well if not better than Oregon and Washington seedlots.

Provenance and seedlot variation

Height growth. There were significant seedlot differences in height growth at all sites ($p<0.001$). Multiple range tests showed that only the seedlots with extreme high and low values were significantly different from each other, and these are not shown in Tables 5-7 for reasons of clarity. F ratios for seedlots were significant at the p 0.001 level at all sites except Hanmer, at the p 0.05 level. Interestingly, some clear trends in growth rate with latitude of origin (provenance ranked from south to north) are evident and these vary somewhat at different sites. The southernmost provenance from Los Padres National Forest (lat. 35°49´N) grew the slowest at all sites. At the worst site, Gowan Hills, native population seedlots and US seed orchard seedlots from latitude 40° northwards were growing best, with little differentiation among provenances from northern California to Washington. Those from as far south as Pt. Reyes were at most 0.5m shorter than the best-grown seedlots. At Beaumont and Waipori there was a similar situation, with better-grown seedlots coming from provenances scattered from San Francisco to Washington. At Hanmer, the better-grown provenances were from Navarro river northwards to Coos Bay in central Oregon. At Golden Downs however, best growth came from northern California coastal provenances.

Unfortunately in these seed source trials, apart from a few progenies from Weyerhaeuser seed orchards, no native population seedlots north of Rockport, California were included because seed was short and this was used for the progeny trials. In those trials progenies from seven provenances from Brookings (lat. 42°06´) to Siuslaw National Forest (lat. 44°10´) were included. The relative performance of these on the higher altitude sites will have to be inferred from future assessment of the lower altitude progeny tests, especially the one at Gowan Hills.

It seems apparent from the indications provided by the Weyerhaeuser orchard progenies that at the higher altitude, more exposed sites in the South Island from Hanmer southwards, coastal provenances from about latitude 39° in California (Navarro river) northwards into Washington have grown almost equally well. On the other hand, at lower altitude sites such as the southernmost progeny test at Gowan Hills (altitude 300m, lat. 45°54´), height growth of provenances from north of 43° was less than of the provenances from further south. In the progeny test at Golden Downs (lat. 41°33´) early height growth of provenances from Russian river (lat. 38°21´) to Coos Bay (lat. 43°20´) was best, whereas at Kaingaroa (lat. 38°17´) the best early height growth was from the provenances from the Californian coast between latitudes 38°-41°.

The height growth of NZ seed stand seedlots in relation to their provenance origins supports these trends. The three seedlots of Ft. Bragg, Californian origin (seedlots 900, 901 & 903) averaged 2.36m at Gowan Hills and have grown a little less than the seedlots 903 & 904 from Eyrewell and Mt. Thomas of south Oregon origin and more than the seedlots of Washington origin from Beaumont and Kaingaroa (906 & 902). At Beaumont, Waipori and Hanmer the ranking is similar. At Golden Downs, however, the Ft. Bragg material (seedlots 900, 901 and 903) shows a clear advantage over the other NZ seedlots (as it does at the lower altitude progeny test sites, particularly at Kaingaroa).

Diameter at breast height was measured only at Waipori and Hanmer and there were strong correlations there of 0.87 between provenance mean height and DBH at each site, indicating that height was still at this stage, a good predictor of diameter and thus volume growth.

Bole straightness. There were no significant differences among provenance mean straightness scores (Table 6) at all sites except at Beaumont where only the best and worst scoring provenances were significantly different. At this site seedlot 900 from the Rotoehu seed stand had the lowest mean score of 4.48, which was not repeated at any other site and is probably anomalous. The Los Padres provenance 808 (the slowest grown) was consistently the straightest at all sites. There were no latitudinal trends amongst the provenances in straightness, and no evidence that the more northern provenances from Washington and Oregon were any straighter than the Californian. Least squares mean straightness across sites (Table 8) varied by no more than half a point on the 1-9 scale, apart from the Los Padres provenance, and among NZ seed stands, the Ft Bragg origin seedlots averaged 6.16 versus 6.50 for Eyrewell and Mt.Thomas seedlots, and 6.34 for Washington-origin seedlots from Beaumont and Kaingaroa.

Malformation. Differences among provenances in malformation score were significant only at Beaumont and Golden Downs. At Beaumont the two seedlots from Eyrewell and Mt Thomas were least malformed, averaging 7.31 but these high scores were not maintained by other seedlots of Oregon origin. There were no latitudinal trends in malformation scores at Golden Downs where form was much better and seedlot means varied only from 8.26 to 8.97. Least squares provenance means across sites showed a range of scores from 6.94 to 7.64 (Eyrewell).

Acceptability. A composite trait that included good growth, stem form and health, only showed significant differences among seedlots at Golden Downs. Here acceptability varied widely from 0.44 for seedlot 812 from SP Taylor State Park, north of San Francisco, and 0.48 for the southernmost seedlot from Los Padres National Forest, to 0.97 for the NZ seed stand at Rotoehu, of Ft. Bragg origin. The three NZ seedlots from Fort Bragg all performed well at Golden Downs, better than nearly all native provenance seedlots, due to a combination of some improvement from silvicultural and natural selection, and provenance. The other NZ seed stand lots did not approach the Fort Bragg material in acceptability. There were no latitudinal trends in acceptability score, apart from the poor performance, mainly poor growth, of the Los Padres provenance.

Needle retention was assessed only at Golden Downs, the only site where there was apparent *Phaeocryptopus* infection. The worst-affected seedlots were from the two southernmost provenances, Los Padres and San Francisco Water Reserve, with scores of 2.15 and 1.9 (Table 8). There was some indication of better needle retention from more northern provenances but there are few seedlots in these trials from Oregon and Washington. The best seedlot for needle retention overall was seedlot 902, from a second-generation stand in Kaingaroa forest of

Washington origin. Possibly the more humid climates of both Washington and Kaingaroa forest provided natural selection for resistance to the fungus. Of the three seed stand seedlots of Fort Bragg origin, 900, 901 and 903, that from Golden Downs, where conditions are least conducive for *Phaeocryptopus* infection, showed much poorer needle retention than the second-generation seed stand from Kaingaroa.

The long term effects of altitude and exposure on Douglas-fir growth have been demonstrated in two older trials. At one site, Glendhu, altitude 650-720m, near Waipori, an area of maximum exposure was selected by the use of "tatter flags" and a number of forest tree species were planted in 1981 to test the effects of exposure on growth. Douglas-fir suffered serious malformation initially, but grew reasonably well after canopy closure. The other site, Cartwheel Hut, altitude 600m, near Beaumont, was a high-altitude extension of eight seedlots of the 1959 series of provenance trials, and only one, from Darrington, Washington, was of coastal origin. John Miller recommended abandoning this trial at age 16 years, because tree form was so bad due to frost and wind damage. An assessment before harvest at age 40 however (P. de la Mare, unpublished data) showed provenance mean heights of 19-23m and provenance mean diameters at breast height from 330-380mm, with the Darrington, WA, and Mendocino, CA provenances the best grown. Douglas-fir evidently has a remarkable capacity to persist and produce a stand on such exposed sites.

Levels of Genetic Improvement

The seedlots in the trial represented three basic levels of genetic improvement. Native provenance material was expected to have the lowest level of improvement, but this might be offset by provenance effects. Seed stands were expected to show better adaptation to New Zealand conditions, helped by rigorous culling to around ten per cent of the original stocking. Seed Orchards were expected to show best gains, although most were first generation orchards where the parents were selected for performance in North American, rather than New Zealand conditions.

In general, the seed orchard seedlots performed well across the board looking at the means across all sites (Table 9), with very slight provenance effects. The New Zealand seed stand seedlots also performed well across the board, with the Fort Bragg seedlots being most vigorous and outperforming the Seed Orchard seedlots on some sites. The Eyrewell seed stand was often the best for form, in marked contrast to the performance of a seedlot from its parent stand at Ashley, which was near the bottom for form in the 1971 trials.

The performance of the Californian native provenance material was also quite good, as there had been fears that some might fail completely on harsh sites. In general, they usually lagged behind the seed orchard or seed stand seedlots in growth and in form, although the Navarro River seedlot showed a potential for excellent growth on some sites.

Correlations between traits and between performance at different sites

Correlations between seedlot means at each site (Table 10) show a significant negative correlation between height and straightness at three out of five sites. This implies that taller seedlots have poorer stem straightness. These are phenotypic correlations that probably reflect that taller trees and seedlots get more wind damage. There were also significant positive correlations between height and needle retention at Golden Downs (better grown provenances are less susceptible to needle cast) and of malformation score and needle retention (better-grown provenances suffer less malformation), which may be related to difficulty in seeing malformation where foliage is thick.

Table 10. Correlations among seedlot means

Traits	Gowan Hills	Beaumont	Waipori	Hanmer	Golden Downs
Height & straightness	-0.47**	-0.43*	-0.15	-0.43*	-0.28
Height & malformation	0.11	0.07	0.05	0.21	0.23
Straightness & malformation	0.18	0.27	0.05	0.12	0.22
Height & needle retention					0.41*
Malformation & needle retention					0.40*

Seedlot mean heights show fairly consistent and significant correlations amongst sites of 0.39-0.70 (Table 11), except those with Golden Downs that were much lower. This confirms the observations of the within-site rankings of seedlots discussed above. There were weak significant correlations of seedlot mean straightness among higher altitude sites but not with Golden Downs. Inter-site correlations of malformation scores were not significant, except in one case, reflecting the lack of significant provenance effects for this trait.

Table 11. Across-site correlations of seedlot mean height

Site	Gowan Hills	Beaumont	Waipori	Hanmer
Beaumont	0.51**			
Waipori	0.70***	0.53**		
Hanmer	0.47**	0.57**	0.24	
Golden Downs	0.13	0.32	0.39*	0.32

CONCLUSIONS

There were strong apparent effects of exposure and lower temperatures on early (eight-year) height growth, stem straightness and malformation (forking) of Douglas-fir, both related to the altitude of the planting site. Trees grew much slower at the highly-exposed, 630m-altitude Gowan Hills site which had lowest (worst) average straightness and malformation scores, whereas the trees at Beaumont which was also very exposed but at an altitude of 430m, grew almost twice as fast but showed equally low straightness and malformation scores. Altitude and latitude are directly related to mean annual temperature but latitude showed a weak influence on growth in the three widely-separated progeny tests, all at altitudes of ca. 300 m.

At the four “hard” trial sites (except Golden Downs) there were significant seedlot differences in height growth yet little difference in the growth performance of provenances from California (ca. 38°N latitude), northwards, even into Washington. However indications of the performance of provenances from Oregon and Washington depended on a few progeny seedlots from different

Weyerhaeuser seed orchards, represented by only one to four progenies each. At these four sites, the NZ seedlots of Fort Bragg, California origin (lat. 39° 15´) were growing at about the same rate as the two seedlots of southern Oregon origin (from Mt. Thomas and Eyrewell) and those of Washington origin (Beaumont and Kaingaroa Cpt. 1061). However at the fifth Golden Downs test site, the northern California provenances from Navarro river, Rockport and the Georgia Pacific orchard were growing best of the native provenances, and the NZ seedlots from Fort Bragg were outgrowing the other NZ seedlots of Oregon and Washington origin by a large margin. A similar outcome was shown at age four years in the progeny trials at lower altitudes.

At the four "harder" sites, the effects of environment on stem straightness, malformation and acceptability have evidently been so strong that they have largely obliterated any effects of provenance. There were no conclusive latitudinal trends in provenance mean straightness and malformation amongst the better-grown provenances. At Beaumont only, the seedlots from Mt Thomas and Eyrewell, originally from coastal southern Oregon, were appreciably less malformed than those from the Ft. Bragg-derived seed stands yet those of Washington origin were no better than the Fort Bragg material.

From these limited results, at higher altitude, exposed and snow-prone sites, there are no apparent advantages or disadvantages in using stock from southern Oregon or Washington coastal provenances over stock of Californian fog-belt origin.

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