FROST DAMAGE IN DOUGLAS-FIR PROVENANCES AT AGE TWO YEARS AT WAIPORI FOREST (DUNEDIN)

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Report No. 26 February 2000

DOUGLAS-FIR COOPERATIVE

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EXECUTIVE SUMMARY

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INTRODUCTION

The Douglas-fir (*Pseudotsuga menziesii*) seed source trial was planted for the Douglas-fir Cooperative on seven sites in July 1996. The 33 seedlots in the trial comprise provenance lots, most made by combining seed from open-pollinated progenies collected from natural stands in the coastal fog-belt region of California and Oregon in 1993 (Low and Miller, 1994). Also included were seedlots from American seed orchards, open-pollinated progenies from American seed orchards and seedlots from New Zealand seed stands.

The seedlot origins are all from the coastal fog-belt of the Pacific Northwest USA, spanning latitudes from 36° to 48°. Flushing time for each seedlot had been scored on a 1-7 scale (1 = not flushed, 7 = fully flushed) in the nursery, at the age of 18 months from sowing, on the first of November 1995 (Low and Miller 1997). Some seedlots differed by more than six weeks in the onset of spring flush.

The 1996 progeny trials include individual progenies which were bulked to make up the provenance seedlots in this study. The progeny trial sites were chosen as top quality Douglas-fir sites with relatively mild climates. The seed source trials were planted on colder and frostier sites (Stovold, 1997), at higher elevations than the progeny trials, to determine adaptation of different provenances and particularly whether the early-flushing seedlots could withstand unseasonable frosts, exposure and colder climates. The location of the trial sites is shown in Figure 1.

An unseasonable frost on the 25th of November 1998 killed much newly-flushed foliage in the Waipori trial, thereby creating an opportunity to rank the seedlots for frost resistance. The frosting scores should also be useful as a co-variate for future growth measurement, as the foliage loss will inhibit growth for at least one season.

EXPERIMENTAL DESIGN, ASSESSMENT AND ANALYSIS

The Waipori site is the lowest elevation site in the seed source series at 300 metres above sea level, yet it is prone to cold air ponding. The trial layout is 10 replicates of 5-tree row plots for 33 seedlots laid out as a randomised complete block design. One seedlot had insufficient trees to plant on this site, so only 32 are represented here. Three New Zealand seed stand seedlots were also deployed as two replicates of 49-tree blocks, adjacent to the row-plot trial.

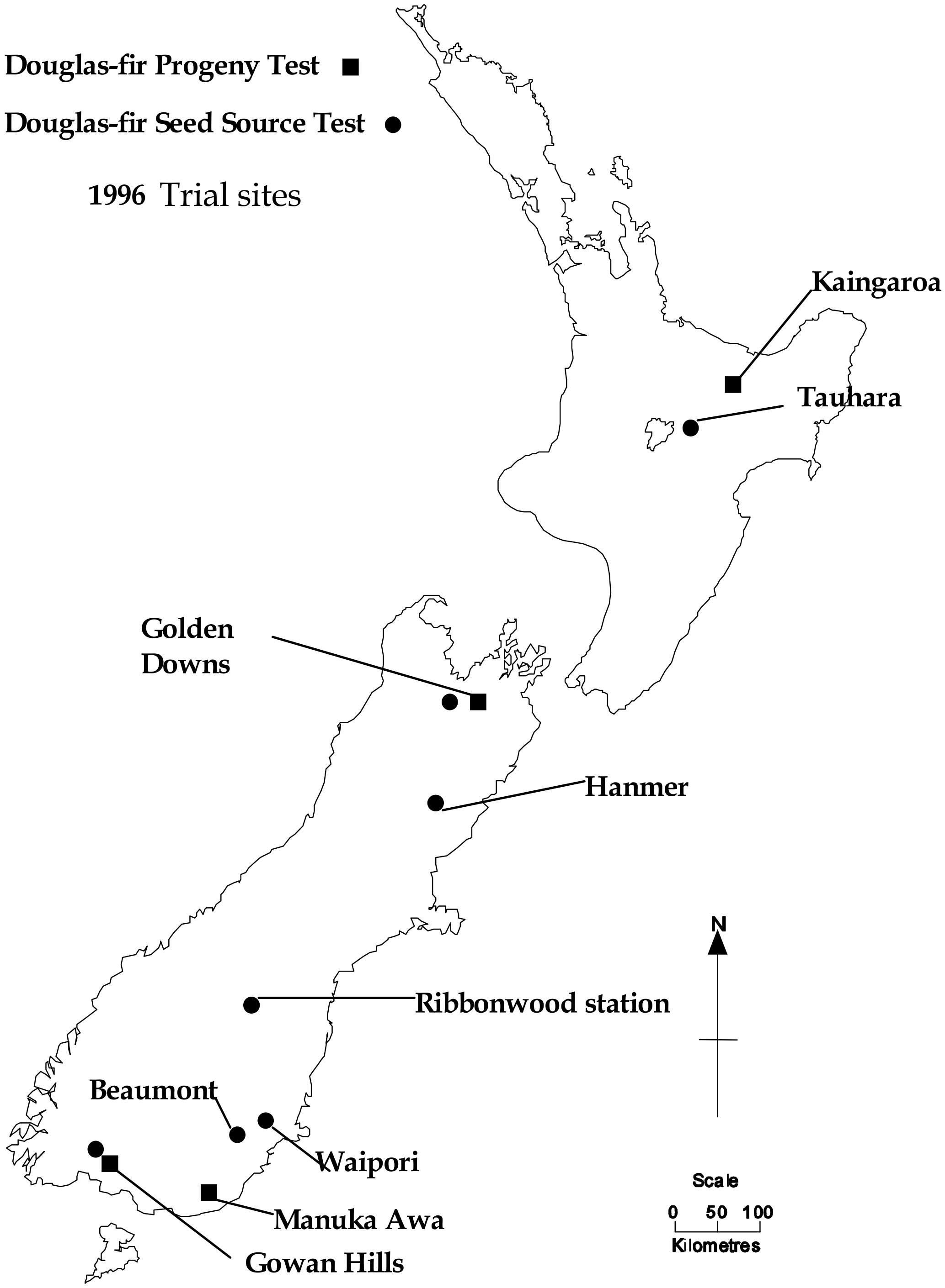
Tree survival was assessed at Waipori in March 1997 (age eight months from planting), at which time stocking of the trial had been reduced to 73%. The cause of the mortality was unknown, and an analysis of numbers of surviving trees showed no significant differences in mortality between seedlots or between replicates.

The flushing was scored at age eighteen months from sowing (Low and Miller, 1997)

The frost damage was scored in March 1999 on a 0-5 scale as follows:-

0 No damage
1 10% of foliage damaged
2 25% of foliage damaged
3 50% of foliage damaged
4 All new flush killed, but tree still lives
5 Tree killed by frost

Figure 1: 1996 Douglas-fir trial sites



An analysis of variance was performed on the data from the row plot trial using PROC GLM of the SAS software package. The same analysis was carried out on the 49-tree blocks separately.

The equation for the model of a randomised complete block design is as follows:-

$$Y_{ij} = \mu + \tau_i + \beta_j + \beta\tau_{ij} + \varepsilon_{ij}$$

Where :

Y_{ij} = the response of seedlot (or treatment) i in replication (or block) j
μ = the overall mean
τ_i = seedlot effect of the ith seedlot
β_j = replication effect of the jth replication
$\beta\tau_{ij}$ = a replication x seedlot interaction effect or plot error
ε_{ij} = experimental error

All terms in the model were assumed to be fixed, as the comparison is limited to the seedlots used on this site. The model was also run setting replication and seedlot as random effects, but the resulting mean squares and F ratios were similar to those of the fixed model.

Seedlot means were estimated by the means option of PROC GLM using the TUKEY multiple range test to show the significance of seedlot differences and a file of seedlot means created by PROC MEANS. A correlation analysis was carried out on these seedlot means using SAS PROC CORR to see if frost tolerance was linked to early survival, flushing time or seedlot latitude.

RESULTS AND DISCUSSION

The mean squares and F tests provided by the analysis of variance are shown in Table 1 for the row plots. There are considerable and significant differences between replicates, reflecting that some replicates were more susceptible to cold air ponding than others. There were also significant differences between seedlots.

Table 1: Statistics from analysis of variance of row plots

Source	degrees of freedom	mean square (MS)	F test over error MS	F test over interaction
Rep	9	9.50	9.77***	6.69***
Seedlot	32	5.05	5.20***	3.56***
Rep*Seedlot	288	1.42	1.46***	
Error	919	0.97		

* probability <= 0.05
** probability <= 0.01
*** probability <= 0.001

Seedlot means from the row plot trial are presented in Table 2 and their means, ranges and standard deviations are presented in Table 3. The seedlots with the lowest frost scores were those which came from northern latitudes such as the Twin Harbours (Washington) seed orchard and those which were late-flushing such as the Kaingaroa strain (originally Washington) seedlot.

However, the Fort Bragg seedlots and the seedlots from Point Reyes and from S.P. Taylor State Park had quite low frost scores, similar to the seedlot from the Beaumont seed stand (Washington origin) which had been expected to have good resistance to frosting.

Table 2: Mean frost score for seedlots in the row plot trial.

seedlot	frost	lat	flush	n.	Provenance
124	1.38 abc	48°05'	3.33	34	USA Weyerhaeuser Twin Harbours 1
224	1.55 abcde	48°05'	4.17	38	USA Weyerhaeuser Twin Harbours 2
324	2.41 fg	48°05'	4.67	41	USA Weyerhaeuser Twin Harbours 3
424	1.03 a	48°05'	3.33	38	USA Weyerhaeuser Twin Harbours 4
mean	*1.64 abcdef*	*48°05'*	*3.88*	*152*	*USA Weyerhaeuser Twin Harbours (WA)*
123	2.20 cdefg	46°30'	5.83	44	USA Weyerhaeuser Long View 1
223	2.02 bcdefg	46°30'	4.50	41	USA Weyerhaeuser Long View 2
323	2.19 bcdefg	46°30'	5.83	32	USA Weyerhaeuser Long View 3
423	1.69 abcdefg	46°30'	5.17	39	USA Weyerhaeuser Long View 4
mean	*2.03 bcdefg*	*46°30'*	*5.33*	*156*	*USA Weyerhaeuser Long View (WA)*
122	1.73 abcdefg	43°25'	4.83	37	USA Weyerhaeuser Coos Bay 1
222	2.02 bcdefg	43°25'	6.00	43	USA Weyerhaeuser Coos Bay 2
322	2.35 efg	43°25'	5.50	40	USA Weyerhaeuser Coos Bay 3
422	2.03 bcdefg	43°25'	5.83	37	USA Weyerhaeuser Coos Bay 4
mean	*2.04 bcdefg*	*43°25'*	*5.54*	*157*	*USA Weyerhaeuser Coos Bay (OR)*
825	2.51 g	40°55'	6.17	39	USA Simpsons Seed Orchard
818	2.47 fg	39°41'	5.83	32	USA Rockport
819	2.23 cdefg	39°27'	5.00	39	USA Georgia-Pacific Seed Orchard
817	1.81 abcdefg	39°25'	5.00	37	USA Noyo River
816	1.87 abcdefg	39°11'	5.67	39	USA Navarro River
815	2.11 bcdefg	38°47'	5.67	38	USA Gualala
814	2.26 defg	38°31'	6.67	35	USA Fort Ross
813	2.00 bcdefg	38°25'	6.67	38	USA Russian River
811	1.51 abcde	38°04'	6.83	35	USA Point Reyes
812	1.33 ab	38°02'	6.67	40	USA S.P. Taylor
809	1.62 abcdef	37°27'	6.83	42	USA S F Water Reserve
810	1.88 abcdefg	37°08'	6.50	41	USA Cascade Ranch
808	2.28 efg	35°49'	6.83	39	USA Los Padres
900	1.56 abcde	39°15'	4.83	41	NZ Fort Bragg (Rotoehu)
907	1.59 abcde	39°15'	4.83	37	repeat of code 900
901	1.83 abcdefg	39°15'	4.67	40	NZ Fort Bragg (K1132)
903	1.95 bcdefg	39°15'	5.17	38	NZ Fort Bragg (Golden Downs)
mean	*1.73 abcdefg*	*39°15'*	*4.88*	*156*	*NZ Fort Bragg seed stands*
902	1.41 abcd		3.67	35	NZ Kaingaroa Strain (K1061)
904	1.82 abcdefg		5.50	35	NZ Ashley, Eyrewell
905	1.69 abcdefg		5.67	32	NZ Ashley, Mt Thomas
mean	*1.76 abcdefg*		*5.59*	*67*	*NZ Ashley seed stands*
906	1.76 abcdefg		4.67	33	NZ Beaumont

The letters following each mean score were produced by the TUKEY multiple range test and any means not sharing a letter are considered to be significantly different at the 95% level.

The mean frost scores for seedlots from New Zealand seed stands are all low and surprisingly similar, with the exception of the very late-flushing Kaingaroa seedlot. Another seedlot which appears anomalous is seedlot 825 from Simpsons Seed Orchard. The parents in the orchard were selected in the fog-belt of Del Norte County, but the orchard itself is situated in Redding, about 80 kilometres inland. There may be some pollen contamination from inland Douglas-fir which is adapted to a different climate.

Table 3: Seedlot means, ranges and standard deviation

Variable	n.	mean	Standard Deviation	Minimum	Maximum
Number	33	37.85	3.15	32.00	44.00
Flush	33	5.39	0.99	3.33	6.83
Latitude	29	41.62	3.97	35.49	48.05
Frost	33	1.88	0.37	1.03	2.51

The differences shown in mean frost scores amongst the Weyerhaeuser seed orchard progenies provide some indication that this trait is heritable within populations. For instance, Twin Harbours seedlot 424 has a score of 1.03 and seedlot 324 a score of 2.41, one of the worst scores of any seedlot in the trial. An analysis of these progenies (Table 4) shows that family in provenance (in orchard) mean square is highly significant. Thus variation amongst half-sib families within a provenance appears to be as great as amongst provenances.

Table 4: Analysis of Weyerhaeuser Seed Orchard progenies

Source	df	Mean square	F test	variance component
rep	9	2.812	1.43	0.0370
prov	2	8.532	8.51***	0.0183
family(prov)	9	6.620	3.36***	0.1194
rep*prov	18	1.065	1.06	-0.0627
rep*family(prov)	81	1.971	1.97***	0.2553
error	345	1.003		1.0026

The correlations of seedlot mean frost scores with flushing score, latitude of origin and number of surviving trees are shown in Table 5. The correlation between frosting and number of surviving trees was low and not significant, so it is unlikely that the earlier mortality was attributable to frost. The correlation between frosting and early flushing (0.43) is significant, but much smaller than the correlation between flushing and latitude (-0.67). The correlation between frosting and latitude is negligible.

Table 5: Correlations of seedlot means

	Number	Flush	Latitude	Frost
Number	1.00			
Flush	0.15	1.00		
Latitude	-0.02	-0.67***	1.00	
Frost	0.11	0.43*	-0.13	1.00

Results of the analysis of the 49-tree plots of three seedlots are shown in Table 6. Replicates showed significant differences reflecting that some replicates were more susceptible to cold air ponding than others. The seedlot means are shown in Table 7. The Fort Bragg seed stand seedlot (coastal Californian origin) showed least frost damage with the Ashley (originally from Oregon) and Beaumont (originally from Washington) seed stand seedlots showing somewhat more damage; in the adjacent row plot trial these seedlots showed the same relative ranking.

Table 6: Statistics from analysis of variance of block plots

Source	Degrees of Freedom	Mean Square	F test
Rep	1	12.89	11.11***
Seedlot	2	7.27	6.27**
Rep*Seedlot	2	0.74	0.63
Error	206	1.16	

Table 7: Seedlot means for 49-tree blocks (row plot means in parentheses)

Code	Mean	Flush score	n.	Description
900	2.36 a (1.56)	4.83	70	NZ Fort Bragg (Rotoehu)
904	2.96 b (1.82)	5.50	71	NZ Ashley (Eyrewell)
906	2.80 b (1.76)	4.67	71	NZ Beaumont

The letters following each mean score were produced by the TUKEY multiple range test and any means not sharing a letter are considered to be significantly different at the 95% level.

CONCLUSIONS

1. There are important and significant genetic differences between provenances in frost damage of this kind

2. There are also as large and as significant differences between the progenies of a single regional seed orchard

3. There is effectively <u>no</u> correlation between latitude of origin and frost damage score.

4. By inference from these and other data, "maritimeness" of climate (position relative to that of the coast) is likely to be important for frost damage susceptibility.

5. Flushing time (itself a trait showing big provenance differences) is only weakly related to frost damage. So the genes controlling these two traits are by no means the same, something that in the past has been assumed to be so.

6. Many fast-grown Californian populations, including the Rotoehu Fort Bragg seed stand seedlot, showed very low frost scores. This suggests that these populations are not inherently any better or worse than the slower-grown Washington provenances for these sites - which may be a significant result with practical implications.

7. We should be cautious about concluding from these results that frosting, which occurs at other sites at slightly different times of year, will show the same patterns and relationships.

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