The 1959 provenance trials – results to age 47 years

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NZ Douglas-fir Cooperative

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ABSTRACT

In 1959, large replicated trials containing a wide range of provenances of Douglas-fir collected from the Pacific Northwest were established at Kinleith, Kaingaroa, Gwavas, Golden Downs, Hanmer, and Rankleburn Forests. Each provenance was established in 22×22m plots, and most replicated 2-3 times on each site, with Kaingaroa sourced seed as a control. In 1994, the Douglas-fir Cooperative funded the placement of permanent sample plots into these trials, with the exception of Rankleburn. This report provides an analysis of the measurements made at ages 45-47 years for the Kinleith, Kaingaroa, Gwavas and Golden Downs trials. Data at age 39-44 from the Hanmer trial is also included. Data from several plots which were installed in the Rankleburn trial by Ernslaw are included in a preliminary analysis but not in the main analysis.

The variables analysed were volume mean annual increment (MAI), Site Index, SBAP and the 500 Index. To provide realistic measures of relative growth rates, it was necessary to adjust raw means for differences in stocking, for plot margin effects, and for selection bias. Also, a recently derived relationship between bark thickness in Douglas-fir and latitude of provenance origin was used to adjust the under-bark volume MAI.

Without exception, all the best provenances were from coastal locations in California or southern Oregon while the poorest provenances were from inland sites. After adjusting for stocking, plot margin effects, and bark thickness, the mean percentage increase in volume MAI of the 10 best coastal provenances over the Kaingaroa control seedlot across the five trials was 32%. However, although the coastal Californian and Oregon provenances performed best in all trials, the level of improvement was greater in trials on warmer sites. At Gwavas, the 10 best provenances averaged 55% better in volume MAI than the control seedlot, while at Hanmer the improvement was only 14%. Other trials fell between these two extremes with Kinleith, Kaingaroa and Golden Downs showing improvements of 40%, 26% and 16% respectively for the 10 best provenances over the control seedlot.

INTRODUCTION

In 1959, large replicated trials containing a wide range of provenances of Douglas-fir collected from the Pacific Northwest were established at Kinleith, Kaingaroa, Gwavas, Golden Downs, Hanmer, and Rankleburn Forests. The locations of the provenances collected covered the natural range of coastal Douglas-fir in U.S.A. but did not extend into British Columbia where this variety of Douglas-fir is also found. The origin of each provenance is shown in Fig. 1 and the site of each trial in New Zealand is shown in Fig. 2. Each provenance was established in 22×22m plots, and most replicated 2-3 times on each site, with Kaingaroa sourced seed as a control. The origin of the provenances, and the number of plots assessed in each trial is given in Appendix 1.

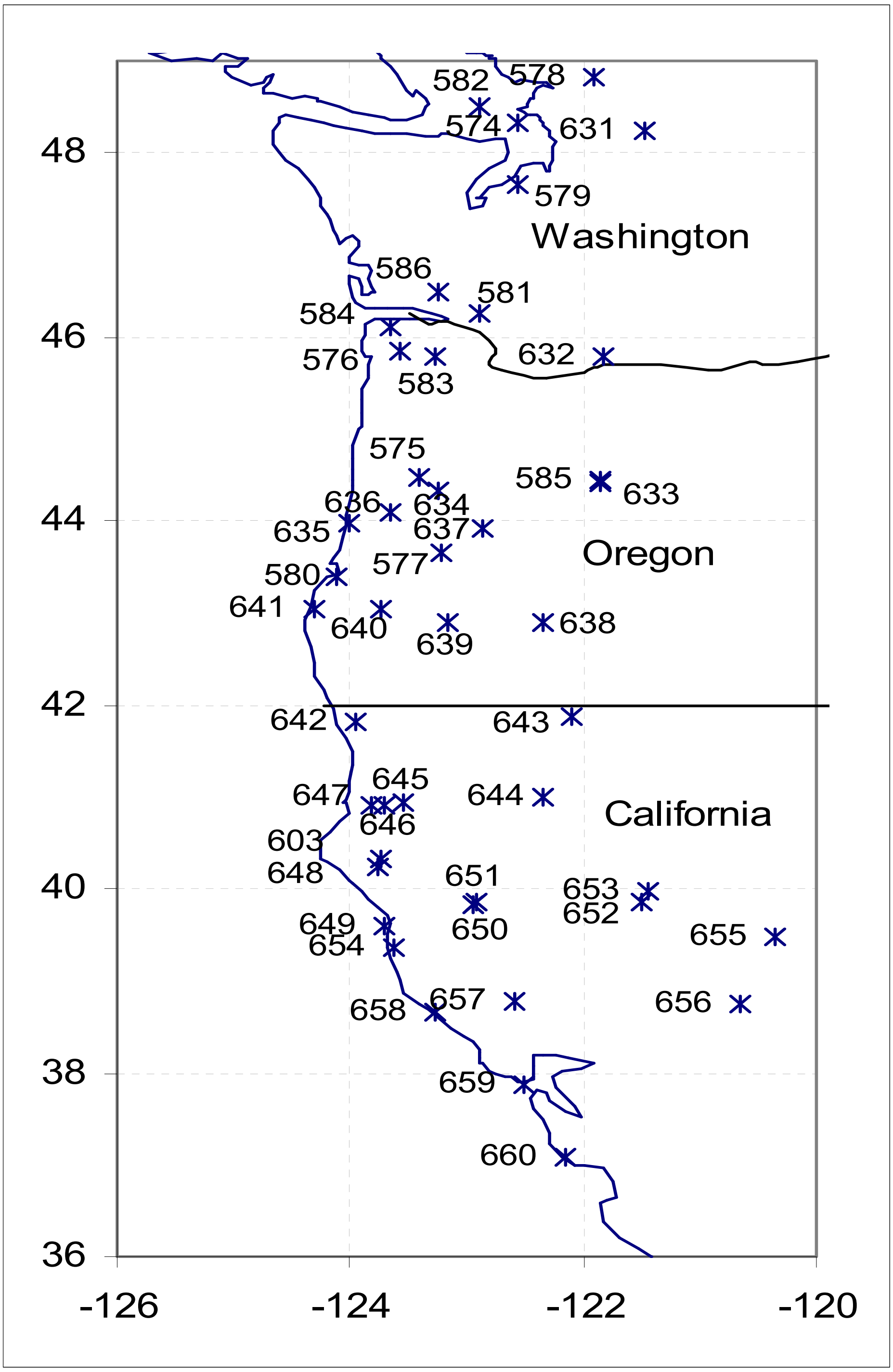


Fig. 1. Map showing the origin of each provenance.

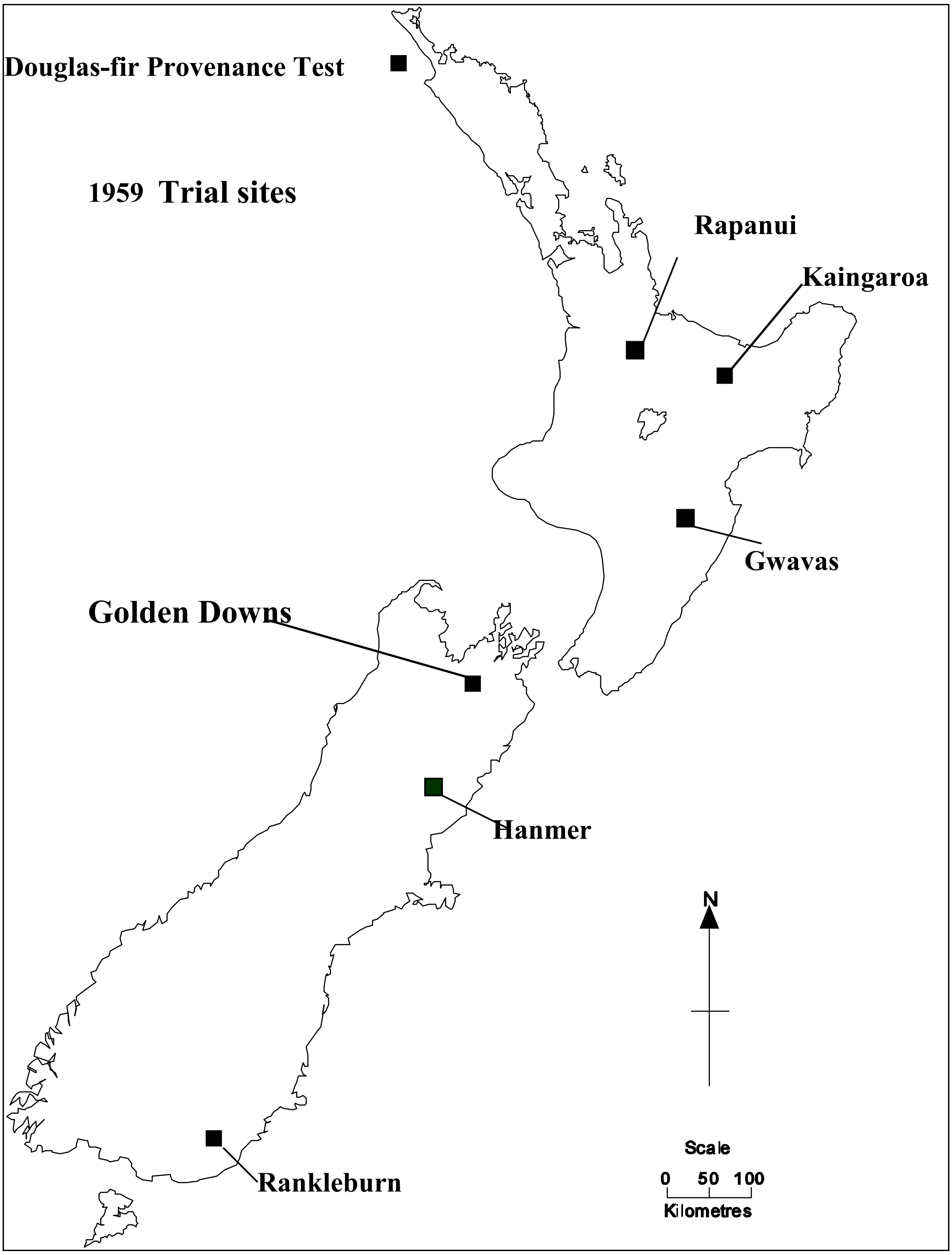


Fig. 2. Map showing the location of each trial.

In 1974, all trials were thinned to waste to a relatively uniform stocking of 550 stems/ha. In 1994, the Douglas-fir Cooperative agreed to fund the placement of permanent sample plots into these trials, with the exception of Rankleburn, where wind-throw following a production thinning placed doubt on the validity of any growth data from that site. Each site has since received at least three measurements. Several of the Rankelburn trial plots have also been measured by Ernslaw One and these are included in a preliminary analysis but not in the main analysis. Generally, only the better provenances were measured, especially in the North Island trials. The number of provenances assessed in each trial and the average number of replicates per provenance is given in Table 1. Locations and climate data for each trial provided by Andrew Dunningham of Ensis is given in Table 2.

Table 1. Trial least squares means of important growth variables. To allow more realistic comparison of trials, all means have been adjusted to the average stocking (535 stems/ha), and to a common mix of seedlots using analysis of covariance.

Trial	Forest	No. provenances	Mean no. plots per provenance	Age of measurement
FR244	Kinleith	21	1.7	47
FR209	Kaingaroa	23	2.5	46
FR249	Gwavas	24	2.8	45
FR224	Golden Downs	42	2.4	46
FR229	Hanmer	45	2.2	39,44
SD231	Rankleburn	8	1.6	44

Table 2. Trial locations, altitude and mean climatic data

Trial	Forest	Latitude	Longitude	Altitude (m)	Mean annual temperature (˚C)	Mean annual rainfall (mm)
FR244	Kinleith	38.4	175.8	470	11.6	1583
FR209	Kaingaroa	38.3	176.4	425	11.2	1547
FR249	Gwavas	39.7	176.4	500	10.9	1523
FR224	Golden Downs	41.3	172.5	400	10.7	1315
FR229	Hanmer	42.5	172.8	500	7.8	1326
SD231	Rankleburn	46.0	169.2	168	9.7	906

An analysis of the trials at ages 38 to 40 years was presented at the 2002 Meeting of the Cooperative (2002 Meeting Proceedings, pages 9-18). This report presents results from the most recent measurements of these trials at age 45 to 47 years. The exception is the Hanmer trial, most of which was felled several years ago. The final measurement in the felled portion of this trial was taken in 1998 at age 39 years and this was combined with the closest corresponding measurement in the remaining replication which was taken at age 44 years in 2003. Using a mixed model randomised block analysis it was possible to combine these two measurements together to get meaningful results from this trial. The Rankleburn plots included in the preliminary analysis were last measured in 2003 at age 44 years.

METHODS

The variables analysed were volume mean annual increment (MAI), Site Index (SI), Site Basal Area Potential (SBAP) and the 500 Index. Raw means of each provenance taken across all the trials could be misleading and required adjustment to take account of a number of potentially confounding factors as listed below:

- Uneven distribution of provenances between trials.
- Stocking - Due to mortality and/or earlier thinning operations, individual plots varied somewhat in stocking. Volume MAI was generally lower in lower stocked plots.
- Selection bias - In trials such as these, potential genetic gains calculated using simple provenance means tend to be over-estimated. This is because, simply by chance, the selected superior provenances will tend to perform better than they would if the trials were repeated.

- Bark thickness. Recent work by McConnon et al. (2004) indicates that provenances from more southerly latitudes of North America generally have thicker bark and hence smaller under-bark volumes for the same DBH.
- Plot margin effects - The 22×22m plots in these trials did not include buffer rows. Because provenance differences were often substantial, plot edge trees of the better provenances often grew with less competition than would occur within a continuous stand of the provenance. Conversely, poorer provenances suffered from excessive competition. These effects could give significant over-estimates of the growth gains of better provenances, and underestimates of the growth performance of poorer provenances, if not taken into account.

The basic method of analysis was analysis of variance (ANOVA) performed using the SAS Version 9 procedure PROC MIXED. The model used was a 2-way ANOVA which included the effects of trial site and provenance, and included stocking as a covariate. The provenance 'least squares' means (LSMeans) provided by this analysis are automatically adjusted for the first two confounding factors listed above. Selection bias can also be corrected using PROC MIXED. This is achieved by 'shrinking' the estimates of better provenances toward the overall mean. Estimates using this approach are known as 'best linear unbiased predictors' (BLUPs) and provide more realistic measures of the likely gain in growth than the unadjusted means. Both LSMeans and BLUPs are presented in this report as both can be appropriate. For determining percentage gain of provenances selected on the basis of the trial results (e.g., the best provenance, or the best 10 provenances), BLUPs are more appropriate. For determining the percentage gain of provenances selected on other criteria (e.g., Coastal Californian provenances), LSMeans are more appropriate.

To adjust for the effects on volume MAI and 500 Index of the thicker bark generally occurring in the more southerly provenances, we used the results of McConnon et al. (2004). They calculated the reduction in under-bark volume for six of the provenances covering the range in latitude. A quadratic regression of the volume adjustment versus latitude was derived from this data (Fig. 3) and used to adjust volume MAI LSMeans and BLUPs.

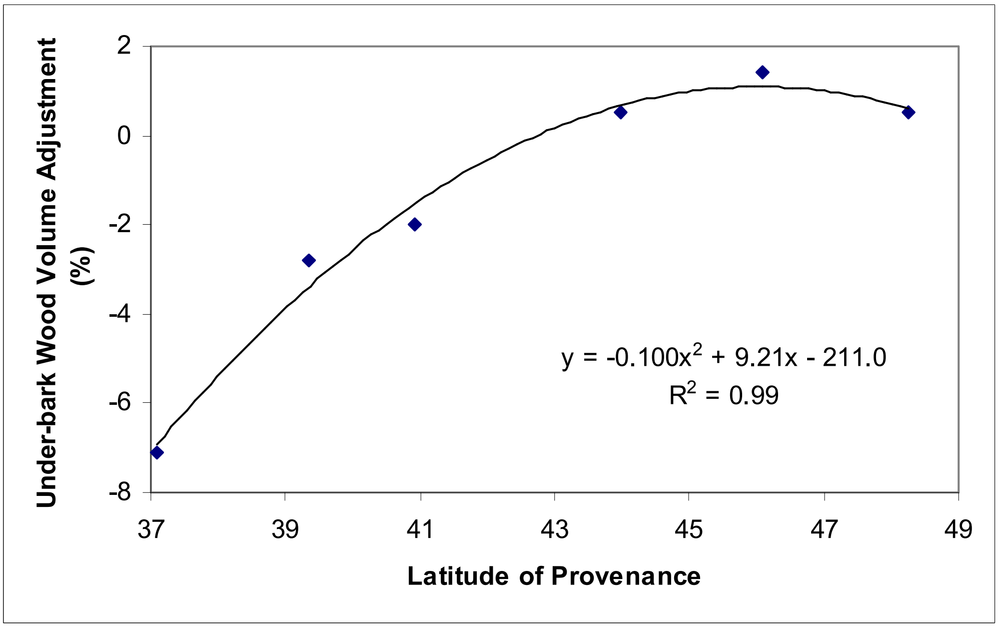


Fig. 3. Relationship between reduction in under-bark wood volume and latitude.

The effect of plot margin on provenance means was estimated as follows. In three of the trials (Kaingaroa, Kinleith and Gwavas), the exact coordinates of trees in each plot were recorded. For these trials, it was therefore possible to obtain provenance means excluding trees within a given distance of the plot margin. A procedure was developed for obtaining means for varying buffer widths. Means were obtained in this way for mean individual tree basal area (BA), height, and volume calculated from height and diameter using STANDPAK volume function No. 37. To determine the effect of plot margins on mean tree size, the ratio of mean tree size of all trees divided by mean size of inner trees was calculated for each plot. A ratio of less than one indicated that edge trees were significantly larger than inner trees in the plot. Linear regression equations were derived between this ratio, and the mean tree size as a ratio of the Kaingaroa control seedlot minus one. These regressions were then used to correct LSMeans and BLUPs for each provenance. Volume MAI was adjusted using the individual tree volume regression, SBAP was adjusted using the BA regression, and SI adjusted using the height regression.

RESULTS

Mean productivity measures for each trial are given in Table 3. Although the trials are located in widely differing locations, productivity levels as indicated by the 500 Index are similar at around 17 to 18 m^3/ha/yr for most of the trials when corrected to a common mix of seedlots using a general linear model (Table 3). The Kinleith and Rankleburn trials are more productive with 500 indices of 22.7 and 24.6, although the latter is based on data from very few plots. Note that despite having the highest potential productivity, the Rankleburn trial had the lowest volume MAI because of its low stocking level caused by windfall following an earlier production thinning. The low volume MAI in the Hanmer trial also reflects its relatively low stocking.

Table 3. Average stocking and productivity indices for each trial. These have been corrected to take account of differences in the mix of seedlots in each trial using general linear models.

Trial	Forest	Mean Stocking (stems/ha)	SBAP (m^2/ha/yr)	Site Index (m)	500 Index (m^3/ha/yr)	Volume MAI (m^3/ha/yr)
FR244	Kinleith	496	1.97	32.8	22.7	22.3
FR209	Kaingaroa	443	1.63	33.1	18.8	18.4
FR249	Gwavas	579	1.92	28.5	17.5	19.1
FR224	Golden Downs	579	1.74	30.5	17.0	16.0
FR229	Hanmer	336	1.80	30.6	17.3	12.7
SD231	Rankleburn	260	2.30	32.5	24.6	12.4

The analysis of variance of volume MAI indicated very significant provenance and trial sites effects (Table 4). This analysis also indicated that a worthwhile improvement in precision was achieved by including stocking as a covariate. While Trial × Provenance interactions were statistically significant, they were of secondary importance compared with the provenance main effect. A graph showing individual provenance means from each trial plotted against the overall mean of each provenance across all trials shows strong positive relationships in all trials (Fig.4). This demonstrates that provenance rankings were generally similar in all trials. However, the slope of the relationship differed between trials indicating that the differences between better and poorer provenances were greater in some trials than others. This appears to be the main contribution to the Trial × Provenance interaction shown in Table 4, and will be examined in greater detail later in the report. Note that only a few of the better provenances were assessed at the Rankleburn trial. This trial was therefore not included in any further analysis.

Table 4. Analysis of variance of Volume MAI across all six trials.

Source	Degrees of freedom	Type 3 Sum of Squares	Mean Square	F Value	Pr > F
Stocking	1	778.9	778.9	84.04	<0.0001
Trial	5	1546.6	309.3	33.37	<0.0001
Block(Trial)	1	1.3	1.3	0.14	0.71
Provenance	44	5303.4	120.6	13.01	<0.0001
Trial × Provenance	113	1835.5	16.2	1.75	0.0003
Error	204	1890.7			

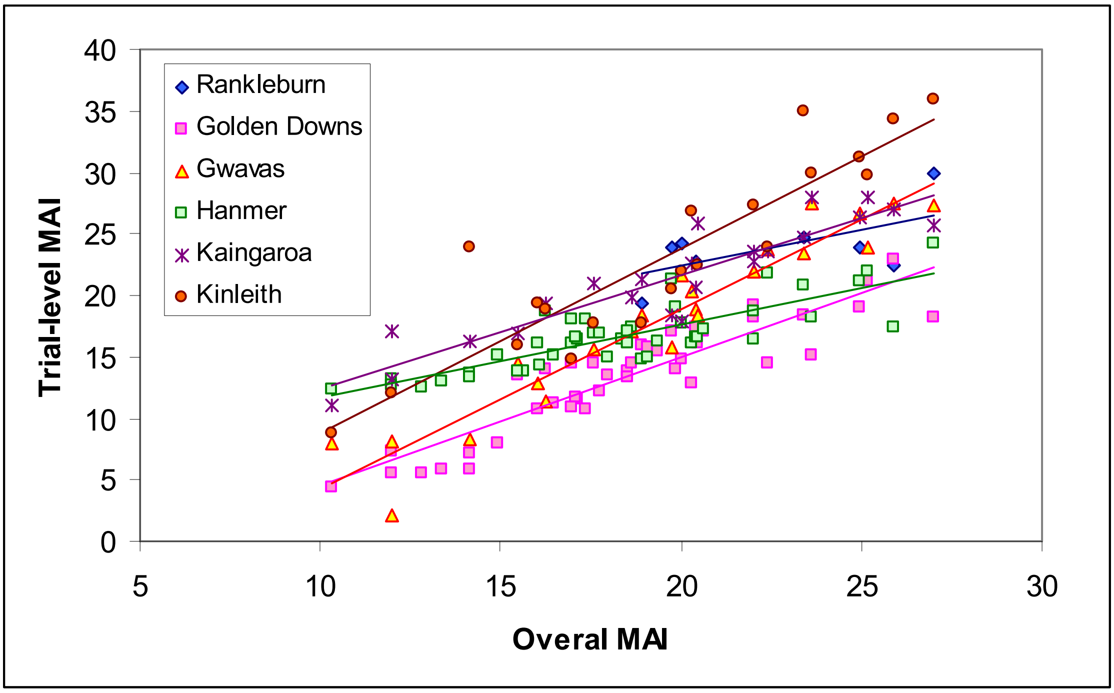


Fig. 4. Mean volume MAI of provenances in each trial plotted against the overall provenance means. Means are adjusted for stocking differences but not for plot margin or bark thickness. The lines are linear regressions fitted for each trial.

Significant plot margin effects were obtained for all the tree size variables (BA, volume and height). The ratio of mean tree size of all trees divided by mean size of inner trees (Reduction_Ratio) was obtained using varying buffer widths. Linear regression equations were derived between this ratio, and the mean tree size as a ratio of the Kaingaroa control seedlot minus one (Ctrl_Ratio). The effect of varying buffer widths is shown in Fig. 5 and indicates that a buffer of 2.5m, representing the outer row of trees, accounts for most of the plot margin effect. For volume using the 2.5m edge adjustment, the derived regressions equation was: Reduction_Ratio = 1.00 – 0.135 × Ctrl_Ratio, $R^2 = 0.18$. The equation for BA was: Reduction_Ratio = 1.00 – 0.182 × Ctrl_Ratio, $R^2 = 0.18$. For height, the equation was: Reduction_Ratio = 1.00 – 0.072 × Ctrl_Ratio, $R^2 = 0.07$. In all cases, provenances poorer than the control seedlot were excluded when fitting the equations as these showed greater variability.

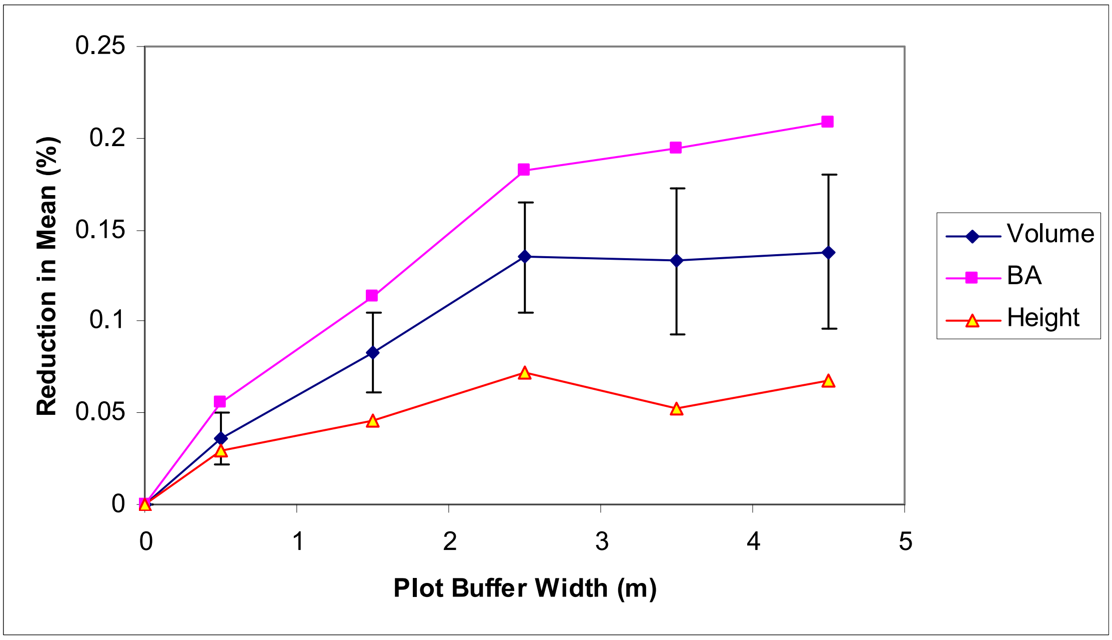


Fig. 5. Effects of excluding trees in buffers of various widths on mean tree size for volume, BA and height. The results show the percentage reduction in tree size required for each percentage point increase in mean tree size over the Control seedlot. Error bars show standard errors for the volume adjustment.

Table 5 shows the estimates of volume MAI, SBAP, SI and 500 Index for each provenance, adjusted for stocking, plot edge effects, bark thickness, and selection bias (i.e., using BLUPs), and ranked on MAI, while LSMeans are shown in Table 6. The percentage increase or decrease in yield of each provenance over the Kaingaroa Control seedlot is also shown. The provenance ranking based on volume MAI is very similar to the ranking based on SBAP (R^2=0.88), 500 Index (R^2=0.93), and SI (R^2=0.86). For reasons that are not entirely clear, the percentage gain over the Control seedlot of the best provenances is greater for the 500 Index than for volume MAI. For example, the best provenance (No. 654) has a volume MAI of 23.3 compared with a 500 Index of 25.5, while the Control seedlot has an MAI of 16.1 and a 500 Index of 16.3. The best 6 provenances, and 7 of the best 10 are all from coastal California. The remaining three of the top 10 are from coastal Oregon. The best Washington provenance is only ranked 19th. Generally, the inland provenances performed much more poorly than the coastal provenances. These results are shown clearly in Fig. 6.

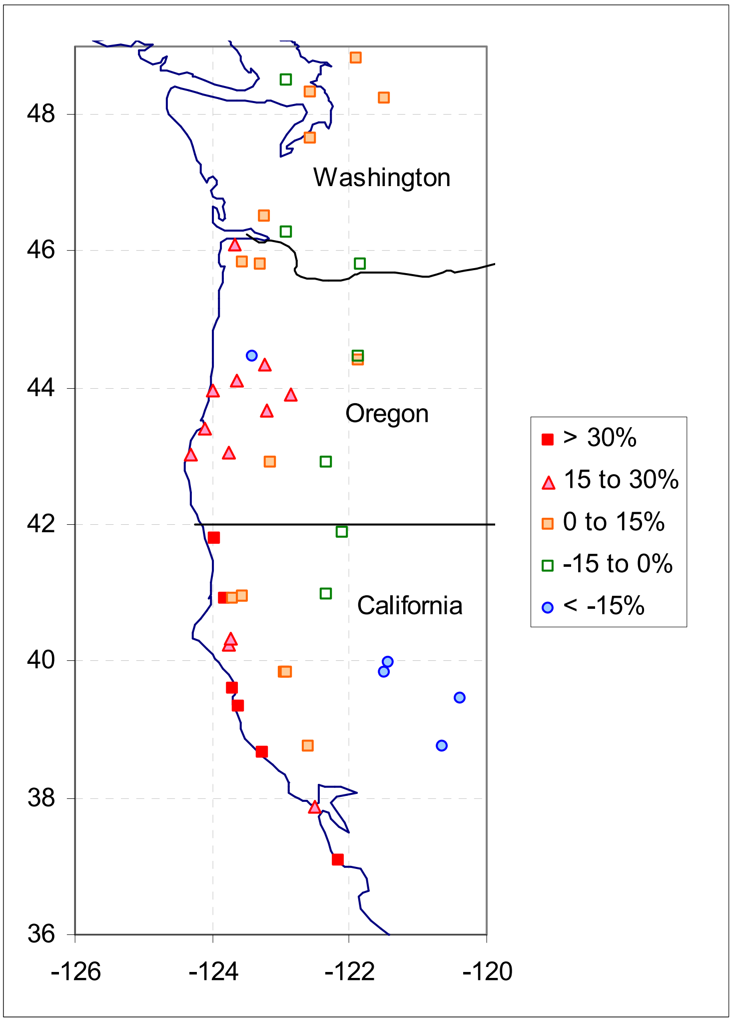


Fig. 6. Volume MAI gain of each provenance over the Control Seedlot, averaged across all trials, against provenance origin.

The various adjustments described above had a considerable effect on these results. Without any adjustment, the best 10 provenances were 46.6% greater than the Control. Adjustment for plot edge effects reduced this to 37.2% while correcting for the thicker bark in these better provenances reduced this to 33.7%. Adjustment for selection bias reduced the gain further to 31.7%. However, this overall gain of more than 30% is clearly of great importance as it implies that selection of more suitable seed sources could provide a dramatic gain in productivity over historic levels.

Table 5. Provenance BLUPS for MAI, SBAP, SI and 500 Index adjusted for selection bias, plot edge effects, stocking, and for MAI and 500 Index, bark thickness. The percentage gain of each provenance over the Kaingaroa control seedlot is also shown.

Provenance	Volume MAI (m^3/ha/yr)		SBAP (m^2/ha/yr)		SI (m)		500 Index (m^3/ha/yr)	
	mean	% gain	mean	% gain	mean	% gain	mean	% gain
654	22.9	41.9	2.32	35.0	33.8	9.7	25.1	50.1
647	22.4	38.9	2.25	31.0	33.9	9.9	24.8	48.0
660	22.3	38.1	2.16	25.8	35.8	16.3	24.2	44.6
658	21.8	35.3	2.26	31.8	34.0	10.5	24.2	44.2
642	21.4	32.8	2.22	29.3	33.2	7.7	24.4	45.7
649	21.1	30.6	2.20	28.3	32.5	5.4	23.0	37.4
635	20.7	28.2	2.08	21.1	32.8	6.5	22.6	34.9
641	20.6	27.7	2.09	21.4	33.2	7.8	22.6	35.1
659	19.7	21.9	2.09	21.4	32.7	6.2	21.1	26.1
584	19.6	21.3	1.84	7.4	32.6	5.8	20.1	19.7
640	19.6	21.2	2.05	19.3	32.0	3.9	21.6	29.0
575	19.4	20.5	1.99	15.8	31.5	2.4	20.6	23.1
580	19.2	19.2	1.93	12.4	33.1	7.5	20.7	23.7
577	18.7	16.1	1.98	15.1	32.0	4.1	20.8	24.1
636	18.7	15.8	1.93	12.6	32.0	3.7	20.1	19.9
637	18.6	15.4	1.87	8.6	31.1	1.0	19.1	14.0
648	18.6	15.2	1.85	8.0	32.3	4.8	19.4	15.7
603	18.5	14.8	1.92	12.0	32.1	4.3	19.1	13.7
631	18.4	14.2	1.87	9.1	31.9	3.7	19.3	15.0
579	18.3	13.2	1.86	8.2	31.4	1.9	19.4	15.8
633	18.2	12.9	1.85	7.4	31.2	1.4	18.6	11.3
574	18.1	12.5	1.62	-5.7	32.1	4.3	17.0	1.6
576	17.9	11.2	1.70	-1.0	32.1	4.2	17.7	5.6
646	17.8	10.5	1.83	6.8	31.9	3.7	18.7	11.5
583	17.8	10.2	1.90	10.4	31.5	2.3	19.7	17.4
578	17.3	6.9	1.83	6.8	31.0	0.8	18.3	9.1
581	17.2	6.7	1.82	6.2	30.5	-0.9	18.5	10.7
586	17.2	6.3	1.76	2.7	31.4	2.1	17.8	6.3
645	16.9	4.6	1.84	7.1	31.6	2.7	18.3	9.2
639	16.7	3.5	1.71	-0.7	30.8	0.0	16.9	0.6
650	16.6	3.1	1.70	-0.9	31.0	0.8	16.4	-2.1
657	16.6	2.6	1.67	-2.6	30.4	-1.2	15.5	-7.7
585	16.6	2.9	1.77	2.8	29.4	-4.6	17.4	3.8
651	16.6	2.7	1.67	-2.7	31.4	2.0	16.3	-2.8
582	16.1	-0.1	1.61	-6.2	30.9	0.4	15.8	-5.4
632	15.7	-2.7	1.54	-10.4	29.8	-3.3	14.3	-14.5
644	15.4	-4.6	1.65	-4.0	30.0	-2.5	15.9	-5.1
638	15.1	-6.7	1.60	-6.9	28.4	-7.9	14.9	-11.0
643	14.5	-10.4	1.60	-7.1	28.9	-6.1	15.0	-10.5
652	14.1	-12.5	1.43	-16.7	27.9	-9.4	13.0	-22.6
655	13.6	-15.6	1.46	-15.0	26.5	-14.0	13.0	-22.6
634	12.7	-21.0	1.34	-21.8	27.9	-9.4	11.9	-29.3

653	12.3	-23.6	1.36	-21.0	25.9	-16.0	11.7	-30.2
656	10.7	-33.5	1.34	-22.1	25.5	-17.3	10.8	-35.3
R530	16.1		1.72	0.0	30.8	0.0	16.8	0.0
Best 10 provenances	21.2	31.7	2.15	25.2	33.4	8.6	23.2	38.6

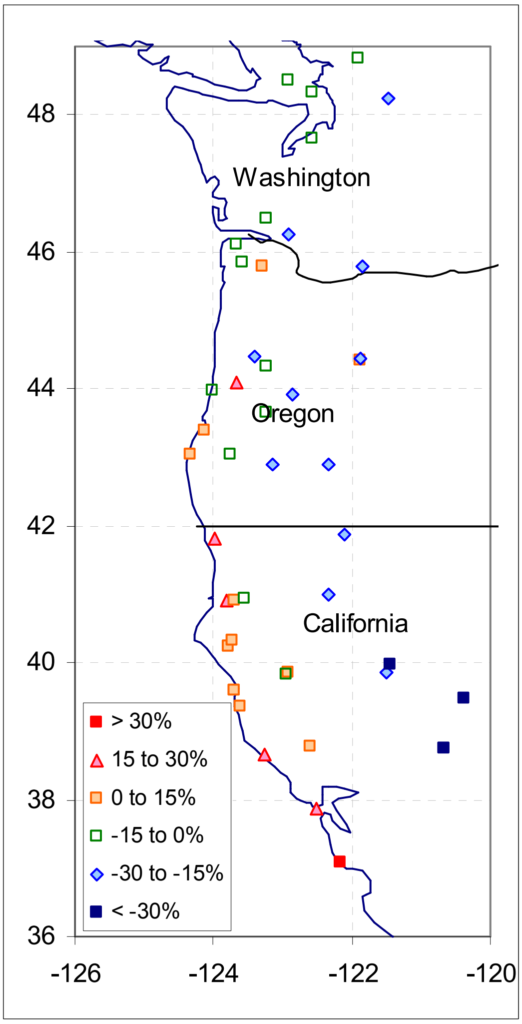
Table 6. Provenance LSMeans for MAI, SBAP, SI and 500 Index adjusted for plot edge effects, stocking, and for MAI and 500 Index, bark thickness. The percentage gain of each provenance over the Kaingaroa control seedlot is also shown.

Provenance	**Volume MAI (m^3/ha/yr)**		**SBAP (m^2/ha/yr)**		**SI (m)**		**500 Index (m^3/ha/yr)**	
	mean	% gain	mean	% gain	mean	% gain	mean	% gain
654	23.3	44.5	2.37	39.2	33.9	10.0	25.5	55.9
647	22.7	41.2	2.28	34.3	34.0	10.3	25.0	52.9
660	22.6	40.6	2.19	28.8	36.1	17.0	24.4	49.5
658	22.1	37.4	2.30	35.1	34.2	10.8	24.3	49.0
642	21.7	34.8	2.26	33.0	33.3	8.1	24.7	51.1
649	21.3	32.4	2.24	31.7	32.6	5.6	23.2	42.0
635	20.9	29.8	2.12	24.6	32.9	6.7	22.9	40.0
641	20.8	29.2	2.12	24.5	33.3	8.1	22.8	39.5
659	19.9	23.5	2.12	24.7	32.8	6.4	21.3	30.6
584	19.8	22.9	1.86	9.3	32.7	6.1	20.1	23.2
640	19.7	22.5	2.07	21.9	32.1	4.0	21.6	32.1
575	19.6	21.5	2.01	18.4	31.6	2.3	20.7	26.7
580	19.4	20.3	1.94	14.3	33.3	7.9	20.8	27.1
577	18.8	16.5	1.99	17.0	32.1	4.2	20.6	26.3
636	18.7	16.4	1.95	14.7	32.0	3.8	20.1	23.1
637	18.6	15.7	1.83	7.6	31.0	0.7	18.5	13.0
648	18.6	15.5	1.81	6.5	32.4	5.1	18.9	15.6
603	18.6	15.2	1.95	14.8	32.2	4.3	19.2	17.6
631	18.5	14.7	1.87	10.0	32.0	3.7	19.0	16.4
579	18.2	13.3	1.85	8.9	31.3	1.6	19.2	17.5
633	18.1	12.5	1.86	9.3	31.2	1.2	18.6	14.0
574	17.9	11.3	1.42	-16.2	32.4	4.9	15.3	-6.4
576	17.7	9.9	1.63	-4.3	32.2	4.5	16.9	3.6
646	17.7	10.0	1.79	5.3	32.0	3.8	18.0	10.1
583	17.5	8.8	1.89	11.2	31.5	2.2	19.4	18.4
578	17.2	7.1	1.85	8.8	31.1	0.7	18.3	11.8
581	16.9	4.7	1.74	2.2	30.0	-2.9	17.1	4.4
586	16.6	3.0	1.72	1.0	31.4	1.9	17.1	4.5
645	16.3	1.3	1.79	5.2	31.6	2.6	17.4	6.7
639	16.3	1.1	1.67	-2.0	30.7	-0.5	16.4	0.1
650	16.2	0.9	1.64	-3.5	31.0	0.3	15.6	-4.6
657	16.2	0.7	1.59	-6.7	30.3	-1.8	14.3	-12.4
585	16.1	-0.1	1.58	-7.0	28.7	-7.1	14.5	-11.2
651	15.9	-1.2	1.60	-5.6	31.4	1.8	15.6	-4.5
582	15.7	-2.7	1.64	-3.8	30.9	0.1	16.2	-1.0
632	15.5	-3.6	1.54	-9.5	29.7	-3.7	14.3	-12.7

644	14.7	-8.8	1.54	-9.7	29.7	-3.6	14.5	-11.2
638	14.2	-12.0	1.52	-10.4	27.8	-10.0	13.9	-14.7
643	14.1	-12.6	1.60	-6.0	28.7	-6.9	15.0	-8.1
652	13.1	-18.6	1.30	-23.6	27.2	-11.9	11.8	-27.8
655	12.5	-22.3	1.28	-24.7	25.5	-17.2	11.0	-32.6
634	12.3	-23.9	1.36	-19.9	27.6	-10.4	12.2	-25.3
653	11.8	-26.4	1.38	-19.1	25.4	-17.6	12.1	-25.9
656	10.1	-37.1	1.38	-18.6	25.0	-18.9	11.5	-29.6
R530	16.1		1.70		30.8		16.3	
Best 10 provenances	21.5	33.6	2.18	28.5	33.6	8.9	23.4	43.4

It is therefore important to determine the reliability of this predicted gain in productivity. There are several potential sources of error in the prediction. Firstly, there is the general variability within provenances and within the Control seedlot in these trials. It is possible to quantify this variability from the standard errors of the BLUPs of the 10 best provenances, and the Control. Using standard formulas for estimating the standard errors of ratios, we can determine that the standard error of the unadjusted percentage gain is 8.3%. Secondly, the plot margin adjustment introduces another source of uncertainty. From the standard errors of the edge-adjustment regression coefficients the percentage reduction in gain was calculated to have a standard error of 4.4%. Combining these two sources of variation, we can determine that the expected gain of the 10 best provenances over the Control seedlot is 31.7±13.7%. The bark thickness adjustment must also be subject to uncertainty but this is likely to have only a minor effect. Our best estimate of the mean percentage increase in MAI of the 10 provenances over the Kaingaroa seedlot is therefore between 18 and 45%. Much of the uncertainty in the above calculation is due to the limited number of Control plots in the trials. When we compared the 10 best provenances with the average of all the Washington provenances including the Control seedlot using the same methodology, the estimated mean gain was lower, but the confidence interval was tighter at 24.4±8.1%.

As noted above, the gain of the superior provenances over the Control seedlot varied between trials. The LSMeans of volume MAI and percentage gains over the Control are shown for each provenance in each trial in Appendix 2. Although the coastal Californian and Oregon provenances performed best in all trials, the level of improvement was greater in trials on warmer sites. At Gwavas, the 10 best provenances averaged 55% better volume MAI than the control seedlot, while at Hanmer the improvement was only 14%. Other trials fell between these two extremes with Kinleith, Kaingaroa and Golden Downs showing improvements of 40%, 26% and 16% respectively for the 10 best provenances over the control seedlot. The performance of provenances at Hanmer and Gwavas are shown in Fig. 7.



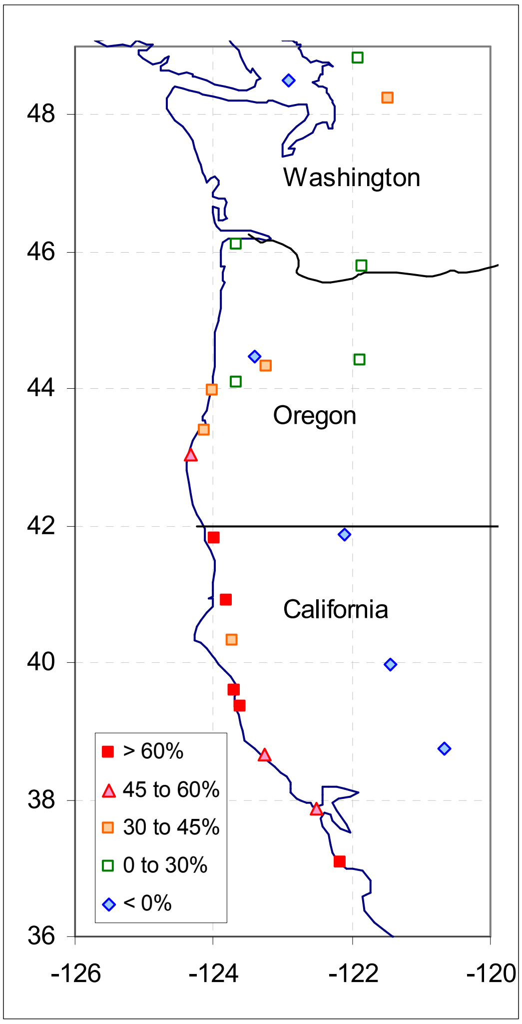


Fig. 7. Average volume MAI gain of each provenance over the Control Seedlot at the Hanmer trial (left) and the Gwavas trial (right) against provenance origin.

CONCLUSIONS

Without exception, all the best provenances were from coastal locations in California or southern Oregon while the poorest provenances were from inland sites. After adjusting for stocking, plot margin effects, and bark thickness, the mean percentage increase in volume MAI of the 10 best coastal provenances over the Kaingaroa control seedlot across the five trials was 32%. However, although the coastal Californian and Oregon provenances performed best in all trials, the level of improvement was greater in trials on warmer sites. At Gwavas, the 10 best provenances averaged 55% better in volume MAI than the control seedlot, while at Hanmer the improvement was only 14%. Other trials fell between these two extremes with Kinleith, Kaingaroa and Golden Downs showing improvements of 40%, 26% and 16% respectively for the 10 best provenances over the control seedlot.

The development of calibration factors for SBAP, Site Index and 500 Index means that projections made by the growth model can now accurately reflect provenance effects. Further development of the model to include genetic improvement should not be necessary.

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Appendix 1. Origin of Provenances and Number of Replicates per Site per Provenance

Provenance	Origin	Altitude (m)	Lat.	Long.	GDwn.	Gwav.	Han.	Kang.	Kinl.	Rank.
FRI 56/574	Camano, Wa.	150	48 20	122 40			2			
FRI 56/575	Summit, Or.	550	44 20	123 20	1	3	2	1	1	
FRI 56/576	Jewell, Wa.	270	45 50	123 40	2		1			
FRI 56/577	Drain, Or.	270	43 40	123 19	2		2			
FRI 56/578	Glacier, Wa.	150	48 50	122 00	2	3	2	1	1	
FRI 56/579	Keyport, Wa.	150	47 40	122 40	2		2			
FRI 56/580	North Bend, Or.	270	43 24	124 13	2	2	2	1		2
FRI 56/581	Castle Rock, Wa.	1070	46 16	123 00			1			
FRI 56/582	San Juan Islands, Wa.	170	48 30	123 00	2	3	3		1	
FRI 56/583	Timber, Or.	250	45 48	123 23	2		1			
FRI 56/584	Olney, Wa.	170	46 06	123 46	1	3	2	3	1	
FRI 56/585	Detroit, Or.	1100	44 27	121 58			2			
FRI 56/586	Pe Ell, Wa.	170	46 30	123 20	2		2		1	
FRI 56/603	Eel River, Cal	160	40 20	123 50	2	3	3	2	1	2
FRI 56/631	Darrington, Wa.	170	48 15	121 35	3	3	1	3	1	1
FRI 56/632	Wind River, Wa.	300	45 48	121 56	2	3	5	2	2	
FRI 56/633	Willamette Nat.For., Or.	1000	44 25	121 58	3	3	3	3		
FRI 56/634	Siuslaw Nat.For. Or.	370	44 28	123 30	2	3	2	3		
FRI 56/635	Florence, Or.	12	43 58	124 06	2	3	2	2		
FRI 56/636	Deadwood, Or.	85	44 06	123 45	3	3	3	3	1	2
FRI 56/637	Dexter Dam, Dexter,Or.	210	43 55	122 58	3		2			
FRI 56/638	Union Ck, Or.	1000	42 54	122 26	2		2			
FRI 56/639	Rogue River, Or.	290	42 54	123 15	3		1			
FRI 56/640	Siskiyou Nat.For. Or	145	43 03	123 51	2		2			
FRI 56/641	Fourmile, Or.	12	43 02	124 25	3	3	3	2	2	
FRI 56/642	Berteleda, Ca.	90	41 48	124 04	3	3	3	4	1	2
FRI 56/643	Klamath Nat.For. Ca.	1600	41 53	122 12	2	1	3	2	1	
FRI 56/644	Lamoine, Ca.	490	40 59	122 26	2		2			
FRI 56/645	Willow Creek, Ca.	180	40 57	123 39	3		2			
FRI 56/646	West of Willow Ck, Ca	480	40 55	123 48	3		2			
FRI 56/647	Mad River, Ca.	200	40 55	123 55	3	3	3	2	3	1
FRI 56/648	Rossy's Ranch, Ca.	530	40 14	123 52	2		2			
FRI 56/649	Dehaven, Ca.	150	39 36	123 48	3	2	3	3	3	
FRI 56/650	Mendocino, Ca.(2500ft)	750	39 50	123 03	3		1			
FRI 56/651	Mendocino, Ca.(4500ft)	1400	39 51	123 01	3		1			
FRI 56/652	Magalia,Ca.	750	39 51	121 36	2		2			
FRI 56/653	Inskip, Ca.	1500	39 59	121 32	3	2	3	3	1	
FRI 56/654	Jackson's State For.Ca	150	39 21	123 43	3	3	2	3	3	2
FRI 56/655	Tahoe Nat.For. Ca.	1250	39 28	120 28	2		2			
FRI 56/656	Placerville, Ca.	820	38 45	120 45	3	2	2	3	1	
FRI 56/657	Middletown, Ca.	430	38 46	122 41	3		2			
FRI 56/658	Stewart Point, Ca.	170	38 39	123 22	3	3	3	3	3	
FRI 56/659	Mt Talmalpeus S.P. Ca	250	37 53	122 37	2	3	2	2	1	
FRI 56/660	Santa Cruz, Ca.	270	37 05	122 15	2	3	3	3	3	1
R54/530	Kaingaroa				3	3	2	3	3	

Appendix 2. Mean provenance volume MAI (m^3/ha/yr) in each trial and % gain over the Control seedlot. Values are least square means adjusted for stocking, plot edge effects, and bark thickness. Provenances are ranked from best to poorest overall. The performance gain of the overall 10 best provenances over the Control are also given.

	All Sites		Golden Downs		Gwavas		Hanmer		Kaingaroa		Kinleith	
Prov	MAI	% gain	MAI	% gain	MAI	% gain	MAI	% gain	MAI	% gain	MAI	% gain
654	23.3	44.5	23.7	37.4	25.9	68.0	12.6	8.7	23.6	30.8	29.7	57.7
647	22.7	41.2	21.0	21.9	25.8	67.3	14.5	25.5	23.5	30.0	26.9	43.0
660	22.6	40.6	18.5	7.4	25.0	61.6	15.6	35.0	22.1	22.2	28.9	53.6
658	22.1	37.4	21.8	26.3	23.3	51.2	14.5	24.9	24.1	33.2	26.7	41.9
642	21.7	34.8	20.5	18.9	25.5	65.1	13.5	17.0	22.3	23.2	31.7	68.7
649	21.3	32.4	17.5	1.7	26.1	68.9	12.0	3.4	24.5	35.3	25.0	32.8
635	20.9	29.8	21.4	24.2	22.2	43.7	11.0	-4.8	21.9	21.1		
641	20.8	29.2	20.9	21.3	23.1	49.9	13.1	13.1	21.4	18.3	21.8	15.8
659	19.9	23.5	16.3	-5.7	23.0	49.1	13.9	19.7	20.8	14.8	25.4	34.9
584	19.8	22.9	19.1	10.8	19.9	29.1	11.2	-3.5	23.5	29.8	21.7	15.5
640	19.7	22.5	19.1	10.7			10.6	-8.8				
575	19.6	21.5	15.9	-8.1	21.5	39.3	11.4	-1.2	21.2	17.4	25.1	33.3
580	19.4	20.3	20.0	16.0	20.8	35.0	11.7	1.5	19.7	8.7		
636	18.8	16.5	20.0	15.7	17.9	16.1	13.9	20.2	17.6	-2.4	21.0	11.5
577	18.7	16.4	18.5	7.2			11.3	-2.1				
648	18.6	15.7	16.8	-2.7			13.0	12.6				
603	18.6	15.5	17.5	1.2	22.0	42.6	12.0	4.1	17.3	-4.4	24.0	27.7
637	18.6	15.2	18.7	8.3			9.3	-19.6				
631	18.5	14.7	19.0	10.1	20.2	31.0	8.5	-26.1	20.0	10.5	17.5	-7.1
633	18.2	13.3	17.8	3.2	19.3	24.8	11.9	3.0	19.0	5.0		
579	18.1	12.5	16.9	-2.2			11.1	-4.4				
574	17.9	11.3					11.2	-3.1				
646	17.7	9.9	16.4	-5.2			11.6	0.3				
576	17.7	10.0	16.7	-3.4			10.4	-10.2				
583	17.5	8.8	15.6	-9.4			11.8	2.0				
578	17.2	7.1	17.8	2.9	17.8	15.3	11.0	-4.9	19.8	9.6	12.3	-34.5
586	16.9	4.7	17.6	2.0			11.2	-3.1			11.6	-38.2
R530	**16.1**	**0.0**	**17.3**	**0.0**	**15.4**	**0.0**	**11.6**	**0.0**	**18.1**	**0.0**	**18.8**	**0.0**
645	16.6	3.0	14.8	-14.5			10.3	-10.9				
650	16.3	1.3	14.4	-16.5			10.6	-8.5				
657	16.3	1.1	13.7	-20.5			11.8	1.6				
639	16.2	0.9	14.2	-18.0			9.6	-17.3				
651	16.2	0.7	13.7	-20.8			12.6	8.9				
581	16.1	-0.1					8.9	-23.1				
582	15.9	-1.2	13.4	-22.3	14.8	-4.3	10.7	-7.4			22.7	20.7
585	15.7	-2.7					8.1	-29.8				
632	15.5	-3.6	16.8	-2.7	17.4	12.7	9.3	-19.6	16.6	-8.1	18.0	-4.3
644	14.7	-8.8	11.4	-34.0			9.9	-14.8				
638	14.2	-12.0	9.8	-43.2			8.6	-25.4				
643	14.1	-12.6	9.0	-47.8	6.7	-56.6	8.2	-29.1	15.9	-12.3	23.3	24.0
652	13.1	-18.6	7.9	-54.0			8.7	-24.6				
655	12.5	-22.3	7.1	-59.0			6.5	-43.8				
634	12.3	-23.9	10.6	-38.8	10.7	-30.7	9.1	-21.7	13.4	-25.8		
653	11.8	-26.4	7.1	-58.9	4.6	-70.0	8.0	-30.8	16.8	-7.1	30.1	60.1
656	10.1	-37.1	6.8	-60.5	7.6	-51.1	5.9	-48.6	11.0	-38.9	20.4	8.3
Top 10	21.5	33.6	20.1	16.4	24.0	55.4	13.2	13.9	22.8	25.9	26.4	40.4