NEW ZEALAND DOUGLAS FIR RESEARCH COOPERATIVE

A REVISED BREEDING STRATEGY FOR DOUGLAS-FIR IN NEW ZEALAND

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Abstract

A new breeding strategy and revised plan for Douglas-fir has become necessary because of difficulties in executing control-pollinated polycrossing and pair-crossing of 180 grafted selections, made in NZ provenance trials in 1988. A further reason for review and revision has been the lack of selection for wood density and stiffness, regarded now as the most important quality breeding objective for Douglas-fir, both in the NZ selections and the 220 selections made in the USA.

The new strategy is based on open-pollinated progeny testing, seed collected either from the clonal archive (for testing existing selections) or from selected plus trees in a new 100-tree selection programme in NZ stands of second-generation Fort Bragg, (Ca). origin. These programmes will emphasise wood stiffness. Open-pollinated progeny tests will have the dual function of providing estimates of parental breeding values and of providing the future breeding population.

Clonal seed orchards will be immediately established with grafts of phenotypically-selected clones at relatively high stockings to allow roguing on parental breeding values (from the progeny tests). These “rolling front” orchards will be extended with backwards-selected clones as later results are available from the open-pollinated progeny tests.

The two themes of the new strategy will be: rapid progress in progeny testing and breeding-population turn over, and closely-ntegrated establishment of clonal seed orchards. Future development of “family forestry” through vegetative multiplication of control-pollinated seed may also be developed.

Key words: Douglas-fir, breeding strategy, open-pollinated progeny, clonal seed orchards

BACKGROUND AND HISTORY OF DOUGLAS-FIR BREEDING IN NZ

General

Douglas-fir is New Zealand's second most important exotic conifer, though it falls a long way short of radiata pine in both area planted (104,000ha) and current new annual planting area (about 4,000ha). Douglas-fir has been grown in New Zealand (NZ) since the end of the last century, mainly in what were State Forests such as Kaingaroa, Golden Downs, Hanmer and Tapanui. Very little Douglas-fir has been grown north of Rotorua. The main establishment periods have been from 1900 – 1935, from 1950-1970 and from 1990 onwards. Although there was little interest in new planting of Douglas-fir during much of the 1970s and 1980s, restocking of clear-felled stands was maintained. High establishment costs, long rotations (about twice those of radiata pine), modest value and low profitability tended to discourage expansion, and so did Swiss needlecast (caused by the fungus *Phaeocryptopus gaeumannii*) and insect defoliation.

From 1988, there has been renewed commercial interest in the species, owing to high values of Douglas-fir timber and also a recognition that on some higher-altitude, snow-prone sites especially in Otago and Southland, Douglas-fir performs better than radiata pine. An important factor in this re-evaluation of the cultivation of Douglas-fir has been the realisation that Californian and southern Oregon coastal fog-belt provenances are growing much faster than the seed used for planting, between 1900 and 1980. The superior stiffness of Douglas-fir, especially of its juvenile corewood, and the degree of natural durability of its early-forming heartwood can produce timber much better suited to structural uses than radiata pine.

Provenance testing

A strong programme of provenance research in Douglas-fir was started in 1955 by I.J. Thulin (Sweet 1964). Large provenance trials of 35 and 45 provenances respectively were established in 1957 and 1959, on eight and 19 sites respectively, the first series, mostly of commercial seedlots from Washington and Oregon, and the second from seedlots collected by Egon Larsen, from Californian and Oregon coastal populations. Further provenance and local seed-source trials were planted in 1974. Although early results were available at age six years (Thulin 1967; Sweet 1964), it was not until 1974 (Wilcox 1974) that the 12-year results of these trials brought the full realisation that the seed collected from NZ stands of Washington origin (and of Washington provenances) were growing substantially slower than coastal provenances from southern Oregon and California.

First breeding programme

A Douglas-fir breeding programme was initiated by M.D. Wilcox in 1970, following a comprehensive review of literature and other information on Douglas-fir end-products, wood properties and log quality, and their deficiencies (Wilcox 1968). Determination of the breeding objective and selection criteria for the first breeding programme was attempted through two sequential wood property and sawing studies, undertaken to determine the among-tree variation of plank stiffness (by machine stress grading) and its relationship to tree form and wood properties (Shelbourne *et al*. 1973; Wilcox 1974). For the first study, 32 trees were chosen in a single 45-year-old stand at Cpt. 1218, Kaingaroa Forest. The stand, planted at 2.4m spacing ,was quite patchily stocked and had had no thinning or pruning. This facilitated selection of study trees for high and low values for a variety of traits including tree form, growth and wood density in eight "character groups" of two high- and two low-valued trees. Four 4.8-m logs per tree were sawn in the first study and only second logs of 23 trees in the second. Stiffness as a plank was assessed as minimum MOE by machine stress grading of 100 x 50mm framing. From the results of both studies, simple correlations were high (0.5-0.8) between tree-mean minimum stiffness as a plank and branch/knot diameter, log diameter/volume, stem deviation, nodal swelling, and cross-grain asssociated with knots, but were only moderate with density (0.4). In both sawing studies tree-mean stiffness as a plank (by log-height classes) was well predicted through multiple stepwise regression on branch diameter, basic density and stem deviations (R^2=0.62-0.79). In the butt- and second 5-m logs, branch diameter alone accounted for 51-57% of MOE variation.

It was interesting that in a recent 2002 study (Knowles *et al*. 2003) of eighteen 42-year-old trees from a densely-stocked stand of Californian origin at Rotoehu, that most variation in timber stiffness was explained by density (R^2=0.75), while branch diameter only accounted for 24% of the variation in log mean timber stiffness. In this study, timber stiffness was also able to be predicted by microfibril angle. Irregular stocking and the resulting larger and more variable branch diameters were evidently the main drivers of timber MOE in the 1970s studies. These earlier studies measured minimum MoE, (not average), and tested the timber as a plank, not a joist.

Selection of 125 plus trees was carried out in 1969, all in stands of probable Washington origin, planted in the 1920s and '30s in Kaingaroa and Whakarewarewa forests. Selection criteria were superior height and DBH, straight stems, free of malformation, and ,well-distributed, flat-angled and moderate-sized branches. Fortuitously this was accompanied by an excellent seed year in the central North Island in 1969, which enabled the prompt collection of open-pollinated seed from most of the plus trees. 125 open-pollinated progenies of these selections were planted in North and South Island forests in 1972.

A further 60 plus-tree selections were made in 1971, this time including wood density as a selection criterion (following the first sawing study). Trees pre-selected for growth and form were finally selected at the rate of about one in four to five for breast height outerwood density. Open-pollinated progenies of 60 of these were planted in 1973.

The assessment of the 1959-planted provenance trials in 1972 at age 13 years (Wilcox, 1974) latterly showed clearly that provenances from the fogbelt of the Californian and south Oregon coasts were growing appreciably faster in volume than the Kaingaroa landrace and Washington provenances. This finding indicated that the 1969 and '71 selections and their progenies from the Kaingaroa (ex-Washington) stands were unsuitable as the basis for a breeding programme. For this reason, and the lack of industry interest in the species, the Douglas-fir breeding programme was put on hold for the next 14 years.

Second breeding programme

The situation of Douglas-fir breeding was reviewed by Shelbourne (1988), 17 years after it was started, who concluded that to reactivate the programme it would be necessary to make new selections from fog-belt provenances from California and southern Oregon coasts. It was decided in 1988, therefore, to select a new breeding population of ca. 200 parents from these coastal provenances which had been planted in the 1957, '59, '72 and '74 provenance- and seed-source tests and in the Ft. Bragg, Ca. provenance seed stands.. Some selections from coastal Washington origins were also included. Stands descended from the Ashley seed stand, also sampled, were apparently of southern Oregon origin, judging from their relative performance in later seed-source tests, and the Beaumont ("Tramway") seed stand was of Washington origin.

Peter Bolton of Proseed NZ Ltd foresaw an increased role for Douglas-fir and was able to fund the assessment of the provenance trials, the selection of plus trees, and collection and grafting of scion material. The grafts of 186 clones were planted in row-plots as an orchard/archive at Waikuku (near Christchurch, South Island). At the time, prices of Douglas-fir sawlogs from unpruned stands had risen rapidly and relatively more than those of radiata pine sawlogs. There was renewed interest by the industry in growing Douglas-fir and a realisation that the species performed better than radiata pine on exposed, higher-altitude sites prone to wet snow. This greater confidence in Douglas-fir was also reflected in the formation in April 1993 of a new FRI-Industry Douglas-fir Cooperative which combined research in a variety of areas including tree breeding.

The majority of the 1988-90 selections (at age ca. 30 years) came from provenances at six of the sites of the 1959 provenance trials, Kaingaroa, Gwavas and Rapanui (Kinleith) in the North Island, and Golden Downs, Hanmer and Rankleburn in the South Island (Appendix 2). These derived from seedlots collected in the Pacific Northwest by Egon Larsen, each provenance being composed of bulked seed from ten parents, except for the Caspar-Fort Bragg (Californian) provenance. For this provenance, seed from 50 trees was collected and also used to plant seed stands, at Rotoehu and Golden Downs. No more than 12 well-grown trees in total were selected of any one provenance. One tree per plot of about 25 trees was chosen with a combination of better diameter growth, straight stem and light, flat-angled branching. The numbers of selections were limited for fear of inbreeding in the future because of the restricted parentage of each provenance. The intensity of selection at any site was limited because plots, originally of 144 trees, had been reduced to about 25 by selective thinning prior to selection. There were one, two or three plots of each provenance per site at the six sites.

Open-pollinated (OP) seed for progeny testing and further selection was not available from the select trees at most sites and in any case would not have been suitable because the trials contained a majority of poorly-adapted provenances that could be pollen parents. Consequently progeny testing of these clones was planned to be done by first grafting these selected plus trees in a clonal archive or seed orchard where open-pollinated seed could be collected from each clone in the clonal archive, or they could be control pollinated by a pollen mix (for estimating breeding values of the parents) and pair crossing used to create families for a new breeding population. The control pollination option was chosen, and this decision unfortunately turned out to be the wrong one in the light of the subsequent difficulties in achieving the completion of the large numbers of polycrosses and pair crosses that were required.

The selection of parents and seed collection of 220 progenies in the U.S.A.
The restricted size of the genetic resources of the coastal fog belt provenances (mostly in the 1957, ’59, ‘74 trials) was of concern, and one of the first projects approved by the new Cooperative was to select and collect OP seed from parent trees in the coastal fogbelt in Califronia and Oregon in the USA. The objective was to increase the size of the breeding population from 186 to ca. 400 parents/progenies. It was fortunate that this plan coincided with a good seed year in California in 1993. Seed was collected from over 240 select parents from 21 provenances, mostly by an NZFRI crew (Low and Miller 1994) though substantial numbers of open-pollinated progenies were supplied by US companies (30) and the US Forest Service and Bureau of Land Management (84), either from select clones in orchards or from select trees. These progenies were raised in Rotorua and planted in 1996 in three progeny/provenance trials between latitudes 38°S and 45°S, at Kaingaroa, Golden Downs and Gowan Hills. These trials have had a first asessment at age 4 years, and as early as 2008-2010 should be ready for forwards selection of the best trees for further breeding and use in clonal seed orchards.

The 1987-1995 breeding strategy
A breeding strategy was formalised in the Douglas-fir breeding plan of 1995 (Shelbourne 1995) This evolved from the review and plan of 1987 for selecting a NZ group from coastal-fogbelt provenances in the 1957 and ‘59 provenance trials, and also incorporated the 220 open-pollinated

progenies from the USA that were planted in 1996. A key feature of this strategy was the reliance on control pollinated poly- and pair-crossing of the 180 NZ-selected clones to create tests respectively to estimate breeding values of parents and to create a breeding population superline. This strategy has unfortunately failed from a combination of environmental, biological, technological and economic factors. The necessary 180 (pollen-mix) polycrosses on each clone, as the female parent and the 180 pair-crosses for creating the new “NZ Superline” breeding population are at present nowhere near completion. This situation came about for two main reasons. The strategy and crossing plan were probably too ambitious for a programme for a secondary species; the siting of the archive at Waikuku was not optimal for seed production because of an unfavourable microclimate; location of the archive in Canterbury meant that it was difficult and costly to carry out crossing programmes with FR staff; and reliance on Proseed for help in the crossing and seed collection was subject to the competing pressures for them in carrying out the main radiata pine control-pollinated orchard work.

From recent sawing- and wood-property studies, it is apparent that lumber stiffness is likely to be an important breeding objective for Douglas-fir. The 180 parents of the NZ Superline and the 200 parents of the USA Superline were NOT selected for density and /or stiffness, and in the NZ Superline, were non-intensively selected from limited numbers of trees of provenance seedlots.

THE NEW 2004 BREEDING AND SEED PRODUCTION STRATEGY

Introduction

A change of breeding strategy to facilitate the timely progeny testing of parents and to simultaneously create sufficient areas of progeny-tested clonal seed orchards is imperative. ***The principal deficiencies of Douglas-fir genetic improvement in NZ in 2004 are the lack of progeny tests of the NZ superline clones to provide breeding values for selecting seed orchard clones, and the lack of commercial seed orchards to supply improved seed.*** The gains in volume growth that are readily available from provenance selection, plus the gains in growth, form and in stiffness from the breeding population remain unexploited. A revision of the breeding objectives and selection criteria for Douglas-fir is also necessary, in the light of the 1970s sawing- and stress-grading studies and recent new knowledge and understanding about timber stiffness and its relationship with other wood properties (Knowles *et a*l. 2003). Timber stiffness is the second main breeding objective after volume growth rate and yield. Development of tools for assessing stiffness in standing trees offer new opportunities for assessing trees in progeny tests, without expensive destructive testing.

A revised and simplified long-term breeding strategy has been developed to unblock the progress of Douglas-fir improvement. This will be done through future use of open-pollinated (OP) seed for progeny testing as well as breeding-population advancement. This will involve collection of OP seed from the Waikuku clonal archive for progeny testing 180 clones of the NZ Superline. There are also fresh opportunities for intensive phenotypic selection in stands of second-generation Fort Bragg, Californian origin that were not available when selections were made in 1988 (in the 1959 provenance trials). The intensive phenotypic selection of ca. 100 plus trees in second-generation stands for growth, form and wood density/stiffness, and their immediate OP progeny testing will provide clones for orchards in which stiffness will be selected for as a principal target trait (as well as branching habit, bole straightness, growth rate and crown health). The immediate establishment of “Rolling Front” clonal orchards with the best NZ Superline A clones and the new “stiffness” selections is an integral part of the strategy. These will be progressively rogued of poorer clones and extended with grafts of the best clones, as indicated by assessment of the OP progeny tests.

Genetic resources

The NZ genetic resources of Douglas fir are of five types:

1. Stands of known origin, planted as commercial plantations, sometimes given heavy thinning treatments to promote seed production (then called "seed stands") This category includes second-generation stands from seed sources of known origin e.g. Fort Bragg second-generation and Ashley second-generation stands (Appendix 1).
2. Provenance and seed source trials of 1957, ’59, ’74, m& ’96 with different provenances in replicated test designs at several sites (Appendix 2).
3. 180 selected clones of the NZ Superline A, deriving from the above two categories, of known origin and provenance, planted in the Waikuku clonal archive. These are mainly of Californian and southern Oregon fog-belt provenances, and also include some Washington selections (Superline A) (Appendix 3).
4. 220 wind-pollinated progenies of USA selections from 21 stands (= provenances), 14 from the coastal fog belt in California and eight from Oregon (Superline B) (Appendix 4).
5. 150 OP progenies of mainly Kaingaroa (Washington) origin, planted at three sites in 1972 &’74 (Appendix 5).

The gene resources of the species have to date (June 2004) been utilised to select a breeding population of about 400 trees that will recombine the adaptation and variability of a wide variety of coastal populations. There are preliminary indications from the performance of a few controlled crosses between Oregon and Californian parents that this outcrossing could generate some “hybrid vigour”. The prospects for the future genetic improvement of Douglas-fir in NZ are excellent as a result of the diverse gene resources. The emphasis on coastal-fog-belt provenances in the southern part of the species’ range reflects the fact that New Zealand's maritime climate is approximated only in those fog-belt areas, and nowhere else in the USA. Selection of parents from populations further inland, and/or from latitudes from northern Oregon northwards, has resulted in poorer-grown offspring.

Evolution of the breeding strategy

The genetic improvement of Douglas-fir in NZ was started afresh in 1988, making the 1970 selections of Washington origin and their OP progeny obsolete because of new understanding of the critical importance of provenance in creating a breeding population and seed orchards. However, the 1988 restart had the benefit of a sound 30-year background of gene-resource planting and large-plot provenance research, and these trials themselves provided the populations (originally from USA coastal fog belt) for the selection of most of the 1988 plus trees. The 1988 selections and their clones established in Waikuku archive, together with the 1993 selection of parents and collection of seed from 21 populations in California and Oregon formed the basis of the formalised breeding plan of 1995.

The strategy described in 1995 (Shelbourne 1995) was one of “recurrent selection for general combining ability”, with the creation of 15 sublines, each of ca. 27 families, grouped as seven sublines of Superline A (the NZ selected clones from the 1959 provenance trials, grafted at Waikuku archive) and eight sublines of Superline B (the OPfamilies of the selections made in the USA) growing in progeny tests at three sites in NZ. Sublines are simply groups of around 25-30 parents within which future mating should take place for breeding-population turnover (either for CP or OP breeding populations) and between which open pollination (or crossing in CP orchards) will be facilitated in the seed orchard. This ensures that although inbreeding will build up slowly within sublines over generations, the production of seed from the seed orchard will be from unrelated parents, and thus outcrossed (not inbred).

For OP clonal seed orchards, this means that ideally the orchard should consist of one clone from each subline at final stocking. As ca. 20 clones are needed eventually in an orchard, this necessitates 20 sublines. With 420 clones in the breeding population, 15 sublines of 28 clones were chosen as the best allocation of clones and sublines. In a CP seed orchard, for each cross made, it is necessary that the male and female parent come from different sublines. Thus a breeding population of just two sublines will satisfy this requirement (Burdon 1986). This method of seed production, combined with cutting multiplication is currently widely employed for production of radiata pine planting stock. If a successful method for vegetatively multiplying Douglas-fir is developed in future, a similar CP seed orchard technology could be used.

The other main element of the 1995 plan was that progeny testing to estimate breeding values in Superline A would be from controlled poly-crossing, and generating the future breeding population would be done by controlled pair-crossing, both within the Waikuku clonal archive. This work has failed to produce sufficient seed and crosses to complete either poly-crossing or pair-crossing. This has meant that no clones of the 180 in Waikuku can be identified as genetically superior for planting in seed orchards, which has caused the programme to stall and necessitates a new strategy.

Revised breeding objectives and selection criteria

In the 1988 review, selection criteria for selecting trees in the provenance trials were identified as diameter at breast height, bole straightness, absence of forking and ramicorn branching and dense, deep crowns with light flat-angled branching. “Breeding objectives” were not discussed as such in either the 1988 nor the 1995 plan, but were assumed to include growth rate and thence yield (largely through selection of the more southern coastal fog-belt provenances), and improved log quality. Selection for wood density at the rate of 1 among 4 previously selected trees for growth and form traits (as done in the 1971 selection in Washington-origin stands) was proposed but never implemented in Superline A because of costs and shortage of candidate trees in the provenance trials. For USA Superline B, this was not implemented because of cost and feasibility in the seed collection operation.

Recent research in a densely-stocked stand of Douglas-fir of Californian origin (Knowles *et al.* 2003) on variation among and within trees in stiffness as a joist (Modulus of Elasticity), short-clears stiffness and SilviScan-predicted stiffness (the latter mainly through microfibril angle (MFA) and density), has shown that stiffness, the most important determinant of quality in structural lumber, shows high variability among trees of Douglas-fir. Although there is large variation in stiffness within the tree from pith to bark which is determined strongly by MFA, variation in stiffness among trees is largely controlled by density, which itself is highly variable. Improvement in lumber stiffness is an important breeding objective, which can thus be achieved through selection for breast height outerwood density, and/or for high sound velocity transmitted beween points either side of breast height using the IML equipment. This pair of traits in conjunction need to be incorporated as principal selectrion criteria in individual-tree and family selection.

Log quality is further determined by log straightness, knot size, absence of forking and knot distribution. Straight stems, and light flat-angled, well-distributed branching continue to be important selection criteria, though stocking and inter-tree competition have large effects on knot size and on cross-grain associated with knots. Selection for growth rate through individual tree

DBH is the only way of improving volume yield per ha; it is not feasible to select directly for volume- or basal area per ha among numerous families in large plots. Selection for dense long crowns and for needle retention will continuue to be important means of selecting for health and resistance to or tolerance of Swiss needlecast. Superline A parent ortets, growing in the 1959 provenance trials have all been assessed for outerwood density and a subset of them have been asssessed for density, MFA and predicted MOE by SilviScan. This information (later using results of their OP testing) will be used to select clones for a new clonal orchard.

It is recommended that the main change to breeding objectives is to include timber stiffness, and thus the new selection criteria for phenotypic selection of new plus trees and for evaluating progeny should target stiffness (i.e. through wood density and IML sound velocity).

New breeding strategy

It is imperative to facilitate the timely and rapid progeny testing of parents to estimate their breeding values (BVs). This can simultaneously provide a breeding population and the BVs to eventually create sufficient areas of progeny-tested clonal seed orchards to supply the industry with seed. Open-pollinated progeny testing is the most practicable strategy to progress the Douglas-fir breeding population and realise gains by backwards selection of orchard clones. This strategy was used very successfully for radiata pine from 1968 onwards. The plan since 1988 to employ control-pollinated polycrossing and full-sib crossing for the Douglas-fir breeding progranmme has proved ill-advised in our situation. It has failed to deliver the progeny required to estimate breeding values for Superline A parents (for backwards selection for orchards), and to cross the clones to advance the breeding population.

The new breeding plan will utilise open-pollinated (OP) seed for progeny testing and for breeding population advancement, accomplishing this in a revised and simplified long-term breeding strategy (Fig. 1). Provided at least one or two future sites of progeny tests/breeding populations show early and good seed production, the testing of selections by OP seed will reduce the length of the breeding cycle, partly by accelerating BV estimation and partly by accelerating mating of the breeding population. The production of seed with high gains from backwards-selected orchard parents should result, and costs should be reduced.

There is little disadvantage in using OP progenies versus polycross progenies for estimating breeding values of seed parents of wind-pollinated conifers. Use of OP half-sib progenies as a breeding population however may show some reduction in predicted genetic gain (Shelbourne 1992) though this is relatively minor. More serious is the loss of pedigree information inherent in open-pollinated families used for forwards selection. There are greater risks for inbreeding to build up within the breeding population because the sublining system cannot isolate groups of parents fully. Further thought is needed about the impact of pollination among sublines within superlines, though it is practicable to isolate the superlines.

However Lambeth *et al*. (2001) have suggested that polycross mating with a known set of pollen parents in the pollen mix could be used to create the breeding population, as well as create progeny tests to estimate breeding values, if molecular markers were developed to allow paternity analysis of progeny. By inference, open-pollinated mating in a well-isolated clonal archive and progeny test/breeding population could be used in the same way, as there is a finite population of pollen parents. The feasibility of polycross mating with parental analysis was evaluated in a third-generation population of 45 parents of loblolly pine. Unique fingerprints were obtained with all 45 individuals but unambiguous paternal identification was not possible amongst certain related individuals in the population. Avoiding relatedness would resolve this problem. Various scenarios were evaluated, and their use would depend on the cost of genotyping, which is predicted to fall dramatically in the future.

Open-pollinated progenies have been used successfully both as breeding populations and for breeding-value estimation in the early generations of the NZ radiata pine breeding programme. The selection and OP progeny testing of 588 parents of the '268' series in 1969 was followed by both backwards selection of seed-orchard clones and forwards selection amongst the same progenies. '875'-series clones were forwards selected at age six years (and disconnected-diallel-mated in situ) and '880'-series parents were selected at age 11 years, followed by further OP progeny testing. The large size of the initial group of selections has proved valuable as a base for future breeding and for backwards selection of seed orchard clones, based on the OP tests. The open-pollinated progeny tests and grafts of parents were in place in test sites and clonal archives within two years of selection. However, because of the wide-scale adoption of control-pollinated clonal seed orchards in radiata pine, to maintain outcrossing from orchards it was only necessary to maintain two large sublines (Burdon 1986), and control-pollinated crossing for the breeding population was also subsequently adopted.

In future, under OP mating, the existing sublining of the three Douglas-fir Superlines into seven sublines of Superline A, eight in Superline B and a projected four in Superline C make it impossible to maintain the unrelated nature of sublines within Superlines. It would be feasible to plant new OP progenies from Waikuku and OP progenies from a new Superline C separately, isolated from other Douglas-fir. However to isolate seven sublines of Superline A and 4 from Superline C from each other (ready for planting at the same time), would be impracticable.

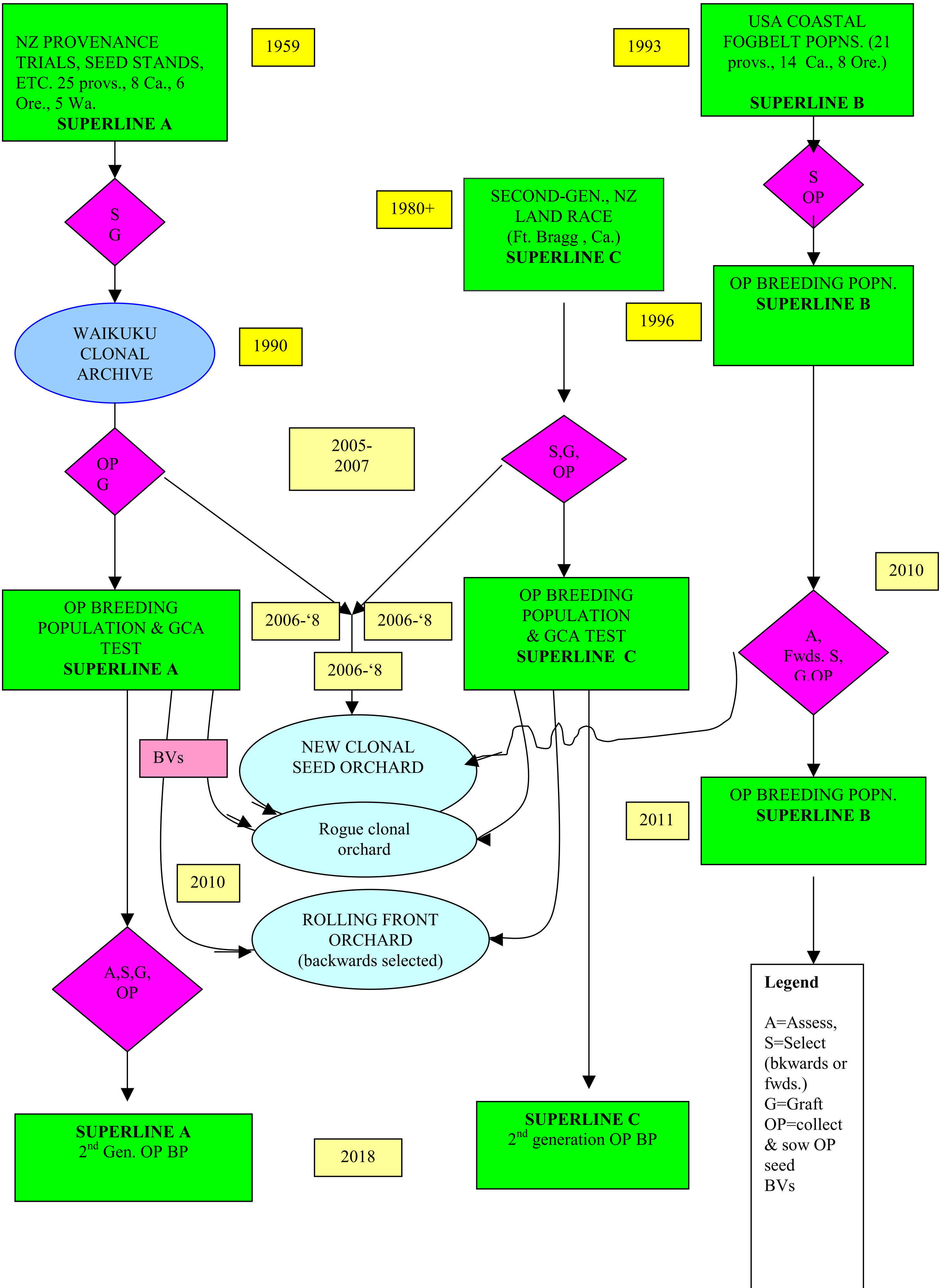
A possible solution in the future would be paternity analysis of any selections made in the OP test proposed. These could then be grouped for orchards and breeding population sublines accordingly. At this stage it still looks desirable to 'GO OP' in the following generation.

As shown in Fig. 1, the new OP strategy for Superline A will involve collection of OP seed from as many as possible of the 180 NZ Superline A clones in the Waikuku clonal archive. The first archive/orchard at Waikuku is composed of 186 clones of Superline A and will provide OP seed for progeny testing and for generating the future breeding population (based on the pollens from within the archive). OP mating will take place across the previously determined subline structure, which cannot be maintained. The future use of sublining within superlines must be resolved following discussion of this plan.

At the same time new clonal seed orchard(s) should be planted of ca. the phenotypic best 40 of the 180 clones at relatively high stocking to allow for intensive roguing on progeny test results. Selecting amongst them is difficult, and would be based on the performance of their provenance in the old provenance trials, plus the ortet's wood density and growth and form traits relative to other parent ortets on the same test site.

Gains in wood density and thus stiffness from Superline A, either in the seed orchard or in the future breeding population will be low because of the relatively low intensity of selection possible for density. Gains in density from ex-USA Superline B forwards selection (see Fig.2) would be potentially greater, involving family selection among 220 families, plus individual-tree phenotypic selection within good families. However the relative unpredictability of such selections compared with backwards selection of clones for use in seed orchards is a disadvantage. Also forwards selection of trees from the USA Superline B trials will not be advisable until they are age 12-15 years i.e. 2008-2011.

DOUGLAS-FIR BREEDING & SEED PRODUCTION



New selection programme for Superline C
A new plus tree selection programme is therefore proposed for three reasons:

1. It should be possible through choosing good seed producing stands of appropriate seed origin to ***collect OP seed from selected trees, and thus immediately establish a progeny test/ breeding population.***
2. By choosing the second-generation Fort Bragg stands as the population base, we know that these are already out-crossed and have a growth rate among the best of all provenances tested.
3. Provided the ***selection for wood basic density and IML sound velocity*** is done correctly, and assuming a moderate to high heritability for these traits, this selection can be sufficiently intensive to ***give substantial improvement in future lumber stiffness***, ***which is not obtainable from any other selections in the whole programme at this stage*** (recall the selection differentials for BH outerwood density in the 1971 selections).

The programme will involve fairly intensive phenotypic selection of 100 new plus trees with good seed production, for ***growth, form and density &/or sound velocity*** in fast-growing South Island stands of second-generation Fort Bragg origin. ***OP seed will be collected as soon as possible for progeny testing these clones and they will also be immediately grafted and planted in the future seed orchard*** at relatively high stocking to allow for roguing. Later, breeding values estimated for these clones/parents from the OP tests will allow backwards selection to both rogue the orchards and extend them (Fig.2), and thus to maximise production of improved seed with high gains, including gains in stiffness. Including some forwards selections from the 1973 high-wood-density OP tests, in spite of their Washington origin, would be desirable.

The breeding strategy proposed therefore is "Recurrent Selection for General Combining Ability", with a sublined breeding population that is open-pollinated in the first generation, in the clonal archive for Superline A, in the USA natural stands in California and Oregon for Superline B and in NZ stands of Ft Bragg, Californian origin (Superline C

Seed Orchards
Open-pollinated clonal seed orchards of grafts are the most efficinet means of producing genetically-improved seed of Douglas-fir in quantity, and use technologies that are well-developed. They have not been without problems in British Columbia and the Pacific Northwest, particularly graft incompatibility has been serious in North America. However compatible-rootstock families have been successfully developed there, which should be accessed for future orchard expansion in NZ. The simultaneous and immediate establishment of "Rolling Front" clonal orchards with the best NZ Superline A clones and the new "stiffness" Superline C selections is an integral part of the new strategy. These will be progressively rogued of poorer clones and extended with grafts of the best clones, as indicated by assessment of the open-pollinated progeny tests.

Open-pollinated clonal orchards will utilise relatively high initial stocking to accomodate early planting of selected clones, later thinned on the basis of the OP test BVs. These "Rolling Front" orchards will be progressively extended as progeny test results become available. At any one time, the orchard should be planted with the known best clones, and orchard composition may change considerably with time.

Control-pollinated orchard practice for Douglas-fir may in future be developed and commercial CP orchards established with backwards-selected superior parents, identified by the OP progeny tests. Siting and management of such orchards in NZ still needs a considerable amount of research. The flowering of CP orchards may be intensively managed and accelerated through gibberellins etc. Pollen contamination from outside the OP orchard is not such a serious problem as with radiata pine because Douglas-fir is not so widely planted, and gains from OP orchards should not be seriously reduced through pollen contamination. However assortative mating of particular parents with high breeding values for chosen traits should eventually provide a means of substantially increasing gains from Douglas-fir breeding. Control-pollinated orchards will enable production of desired superior provenance combinations, and crosses among desired genotypes of high BVs for specific traits.

Control-pollinated seed will initially be only available in small quantities. To give this any real impact on plant production, vegetative propagation techniques, either by cuttings or tissue culture, need to be developed to commmercial levels. These are still a long way off.

Predicted genetic gain in the breeding population and from seed orchards

Recent assessment of the 1959 provenance trials at age 41 years (Kimberley and Knowles, 2002) updated to include the effects of provenenace on bark thickness (McConnon and Knowles, 2004) has shown that offspring of unselected parents from four of the best provenances from California and Southern Oregon fog-belt had 21% more total standing volume compared to the NZ landrace (originally of Washington origin). These trials were located on five widely-scattered sites between Hanmer and Kinleith, with one to three plots/provenance of 144 trees (thinned to 25-30 trees per plot). However, with the exception of Hanmer, the siting of the early provenance trials did not include higher-altitude, snow-prone sites and those in the inland South Island with more continental climates. It was only in 1996 that provenance and local NZ seed-source trials were planted on such sites.

Gains in a single trait have been predicted (Table 1) using prediction methods described for an open-pollinated breeding population in Shelbourne (1992). In the absence of appropriate Douglas-fir data, the actual genetic parameters used were for diameter, heritability 0.2, from a 7-year-old *P. radiata* progeny test. The environmental variance was then adjusted so that additional "traits" with heritabilities of 0.1 and 0.4 were calculated (Shelbourne, 1992).

In the 1995 breeding plan, predicted gains were compared between open-pollinated and control-pollinated breeding populations, which showed a small gain advantage for open-pollinated breeding, in the context of low intensity of selection <u>among</u>, and high intensity of selection <u>within</u> families (designed to maintain effective population size).

In this revised plan, the gain for an OP breeding population was predicted for a single sub-line of 28 parents and their open-pollinated offspring in which the best 19 families and best tree per family of 40 trees were selected as the new parents of this sub-line (breeding population selection is mainly within subline). The best tree in the best family in each subline was also forwards-selected for grafting and planting in a "forwards-selected clonal seed orchard" (see Fig.1, Superline B & Table 1). Gains were also predicted for phenotypic selection in planted second-generation stands of Fort Bragg origin (Superline C), followed by backwards selection of the best of these parents through extending the orchard with the best 15 out of 100 parent clones (on the the basis of their OP test breeding values).

TABLE 1: Predicted percentage gains from breeding population and clonal seed orchards[1]

Breeding population/orchard	Predicted Gains (%) Individual tree heritability 0.1	0.2	0.4
BP of open-pollinated, (half-sib) families	6.9	9.5	13.2
Clonal orchard (from forwards selection in OP breeding population, e.g. Superline B)	12.2	15.6	20.0
Clonal orchard from backwards selection e.g. Superline C	17.7	22.0	26.8

1

[1]These gains do **not** include the gain from selecting Californian fogbelt provenances over the Washington provenances and Kaingaroa land-race.

The seed orchardclones that were forwards-selected from Superline B, had gains exceeding those of the breeding population by from half to three-quarters of the breeding population gain (Table 1). However the backwards-selection of the best 15 out of 100 parent clones of Superline C for an extension of the Rolling Front clonal orchard could yield gains well exceeding those of the forwards-selected orchard from Superline B, and double or more those from the breeding population.

These results show the importance of optimally planning selection intensities in breeding and production populations. Recurrent gain (that is obtained from one generation's breeding population to the next) is critical to the long-term viability of the breeding programme; while the gains from the orchard seed deployed in commercial forest stands, are crucial to the profitability of the breeding programme and of forest management.

These gains are **not** reliable predictions of future realised gains from the new Douglas-fir orchards, but they are reliable indications of the relative gains from breeding and differently-derived orchards (forwards versus backwards selection) for traits of the given heritabilities. The predicted gains for the breeding population apply to selection within each subline of 25-28 parents.

Genetic Gain Trials

Trials for comparison of different, commercially-available, genetically-improved seedlots with a standard unimproved or less improved seedlot have been successfully used in the NZ *Pinus radiata* breeding programme. These trials were originally established to estimate the realised genetic gain from different seed orchards. They have also been used as a basis for research on silvicultural regimes and for developing growth models appropriate for the new breeds, and may have a role here for Douglas-fir. Perhaps their most important role has been demonstrating the benefits of tree breeding to forest managers and others.

In the Douglas-fir context, genetically improved seed from seed orchards is not yet available, though control-pollinated seed in small quantities could be produced at Waikuku. Trials of commercial seedlots from NZ, as well as provenance seeedlots have been made up by bulking families from Superline B into provenance seedlots and these were planted on a range of sites generally “harder”than the trials of the same progenies, planted in 1996.

Future genetic gain trials need to be planted as replicated large plots with at least one buffer row, and preferably two. Plots should be, for example, of 0.1 ha, with 9 rows x 9 rows, 81 trees at 1000 stems per ha, thinned to a final stocking of 500 spha. Around 25 trees should be left in the 5 x 5 row inner measurement plot of 0.03ha after final thinning. At least five replications are needed per seedlot per site. Short-term, small row-plot designs (or single-tree plots) may also be used, with a life of perhaps 10 years, limited by canopy closure and competition before thinning. With five-tree-row plots, 10 replications per site should give good precision (or about 25-30 replications of single-tree-plots.

CONCLUDING REMARKS

The Douglas-fir breeding programme was re-initiated in 1988, with the selection of 180 trees of mainly southern Oregon and Californian coastal fog-belt provenances, mostly from NZ provenance trials. However a fresh breeding strategy has had to be designed for Douglas-fir for two reasons. Firstly, the control-pollinated polycrossing for GCA testing and paircrossing to generate a new breeding population has largely failed to deliver sufficient seed and crosses. Secondly, it has long been realised that gains expected from the NZ parents of Superline A were likely to be modest because of low selection intensities for growth and form traits and no selection at all for wood stiffness, now regarded as prime selection criteria. The new 2004 strategy and future plan has now adopted open-pollinated mating as the means of both establishing tests for general combining ability (breeding value) estimation, and for generating the future breeding population.

The existing Superlines, ‘A‘of NZ selected clones and ‘B’ of USA-selected OP families from natural stands of Douglas-fir, were not based on selection for wood density or wood stiffness and thus were not optimal populations from which to select clonal seed orchard parents. The addition of Superline C will provide OP tests of an optimal population for growth and form, aged 20 years and over, which will provide opportunity for intensive phenotypic selection of plus trees for form, growth and stiffness, and for re-selection among these from results of OP progeny tests. Substantial growth rate improvement will be realised from seed orhard seed, simply by the choice of this provenance, and the plus tree selection and later, backwards selection through progeny test breeding values will be powerful means of realising gains for all selection criteria.

New seed orchard(s) are an integral part of the new plan and will be managed on a “Rolling Front” basis with grafts of parent clones, for which breeding values will be generated after orchard establishment. At any one time these will be planted with the “best” clones through backwards selection from OP test results of Superlines A and C and forwards selections from Superline B of the best trees in the better families. OP progeny tests of both Superlines A and C should be able to be planted quickly. Seed orchard planting of grafts of the parent clones, planted at relatively close spacing, contemporaneously with the OP progeny tests of Superline A and Superline C families, will be later rogued and extended s with the best progeny-tested clones. This strategy will provide seed of high gains in as short a period as posssible. Intensive management of the orchard for early and heavy seed production will be vital to the success of this strategy.

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Appendix 1

Present and Future Seed Stands

stand #	Forest	Compartment	Area (Ha)	Seedlot	Provenance	Planted
RO42	Rotoehu	88	11	70/744	Swanton (CA)	1972
RO2054/1	Kaingaroa	1132	101	R78/34	Fort Bragg(CA)	1981
RO2054/2	Kaingaroa	1159	21	72/774	Korbel (CA)	1974
RO2054/3	Whakarewarewa	19	1.5	72/774	Korbel (CA)	1974
RO2054/3	Whakarewarewa	16	21.9	72/774	Korbel (CA)	1974
RO2054/4	Rotoaira	28	2.9	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	16	5.2	HO68/621	Bandon (OR)	1975
RO2054/4	Rotoaira	31	4.5	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	1	8.7	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	11	0.1	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	27	3.4	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	24	2.9	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	19	1.7	HO68/621	Bandon (OR)	1975
RO2054/4	Rotoaira	20	1.2	HO68/621	Bandon (OR)	1975
RO2054/4	Rotoaira	29	3.9	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	22	10.8	HO68/621	Bandon (OR)	1976
RO2054/4	Rotoaira	25	0.7	HO68/621	Bandon (OR)	1976
WN357	Ngaumu	392	7.3	70/744	Swanton (CA)	1972
NM6	Golden Downs	75	4.5	70/744	Swanton (CA)	1972
NM7	" "	48	23.1	72/774	Korbel (CA)	1974
NM8	" "	340, 342	19.4	72/774	Korbel (CA)	1974
NM9	" "	63	4.5	C69/B22	Ashley (NZ)	1972
NM10	" "	214	5.2	C69/B22	Ashley (NZ)	1972
CY22	Ashley	12/5	3.5	Golden Downs via Tapawera		1942
CY28	Eyrewell Main Race Rd		3.0	C66/518	Ashley (NZ)	1969
CY31	Ashley	150	17.0	C69/B22	Ashley (NZ)	1971
CY33	Mt Thomas	1/1	5.0	CY69/594	Ashley (NZ)	1973
CY34	Eyrewell	26	0.7	72/774	Korbel (CA)	1974
CY584/1	Geraldine	307	12.0	72/774	Korbel (CA)	1974
CY584/2	Geraldine	209	21.2	72/774	Korbel (CA)	1974
CY584/2	Geraldine	110	9.2	72/774	Korbel (CA)	1974
CY584/3	Eyrewell	46	18.5	6/2/79/011	Ashley (NZ)	1982
SD5	Beaumont	17	5.5	S48/405/NM48/40	Tapanui	1952
S522/1	Otago Coast	158	47.2	72/774	Korbel (CA)	1975
S522/2	Berwick	125	5.5	72/774	Korbel (CA)	1975
S522/3	Naseby	23	24.0	72/774	Korbel (CA)	1975
S522/4	W. Tapanui	113/116	8.0	72/774	Korbel (CA)	1975
S678	Pomahaka	201	13.8		CA ex prov tests	1984

N.B. There are also hundreds of hectares planted from Fort Bragg, Ashley and Beaumont seed stands from 1981 onwards

Appendix 2.

Seedlots in provenance trials and seed source tests

1957 Provenance trial

Seedlot	Provenance	Altitude (feet)
166	Eagle Rock, El Dorado County, CA	4300
168	Riverton , El Dorado County, CA	4000
196	Cascadia, OR	1000-1500
280	Nanaimo, BC	1000
281	Forks, WA	1000
282	Wiskah, WA	1000
283	Louella, WA	1000
284	Snoqualmie Pass, WA	1000-1500
285	Ashford, WA	1000-1500
328	ELMA, WA	1000
329	Cascadia, WA	4000
379	Wind River Experimental Station, WA	750
381	Palmer, OR	2200
401	Dusky Forest, NZ	600-1100
452	Cowichan Lake, BC	10
477	Vancouver Island, BC	0-500
485	Aleza Lake, BC	?
486	Slocan Lake, BC	2700
493	Sequim, WA	0-500
494	Granite Falls, WA	0-500
495	Darrington, WA	0-500
496	Leaburg, OR	500-1000
497	Estacada, OR	3250
498	Oakridge, OR	500-1000
516	Mt Baker, WA	500
517	Snoqualmie, WA	800
518	Olympic, WA	500
519	Olympic, WA	500-1000
521	Willamette, OR	3000
522	Willamette, OR	1200
523	Siuslaw, OR	1200
524	Rogue River, Or	3500
525	Siskiyou, OR	1500
R/511	Kaingaroa, NZ	1500
R/518	Whakarewarewa Forest, NZ	1500-1900
NM/594	Tapawera/Tadmor, NZ	

1959 provenance trial

FRI/56/574	Camano, WA	0-500
FRI/56/575	Summit, OR	1500-2000
FRI/56/576	Jewell, WA	500-1000
FRI/56/577	Drain, OR	500-1000
FRI/56/578	Glacier, WA	0-500
FRI/56/579	Keyport,WA	0-500
FRI/56/580	North Bend, OR	500-1000
FRI/56/581	Castle Rock,WA	3500-5000
FRI/56/582	San Juan Islands, WA	0-500
FRI/56/583	Timber, OR	750-900
FRI/56/584	Olny, WA	0-500
FRI/56/585	Detroit, OR	3600
FRI/56/586	Pe Ell, WA	0-500
FRI/56/593	Pike NF, CO	?
FRI/56/603	Eel River, CA	500
FRI/56/631	Darrington, WA	550
FRI/56/632	Wind River, WA	1100
FRI/56/633	Willamette NF, OR	3300
FRI/56/634	Siuslaw NF, OR	1300
FRI/56/635	Florence, OR	50
FRI/56/636	Deadwood, OR	250
FRI/56/637	Dexter Dam, OR	700
FRI/56/538	Union Creek, OR	3350
FRI/56/539	Rogue River NF, OR	1000
FRI/56/640	Siskiyou NF, OR	500
FRI/56/641	Fourmile, OR	50
FRI/56/642	Berteleda, CA	300
FRI/56/643	Klamath NF, CA	4500
FRI/56/644	Lamoine, CA	1600
FRI/56/645	Willow Creek, CA	600
FRI/56/646	18 miles from Willow Creek, CA	1600
FRI/56/647	Mad River, CA	700
FRI/56/648	Rossy's Ranch, Miranda, CA	1700
FRI/56/649	Dehaven, CA	500
FRI/56/650	Mendocino NF, CA	2500
FRI/56/651	Mendocino NF, CA	4500
FRI/56/652	Magalia, CA	2500
FRI/56/653	Inskip, CA	4650
FRI/56/654	Caspar Creek, Jackson State Forest, CA	500
FRI/56/655	Tahoe NF, CA	3800-4200
FRI/56/656	Placerville, CA	2700
FRI/56/657	Middletown, CA	1500
FRI/56/658	Stewart Point, CA	500
FRI/56/659	Mount Tamalpais, CA	800
FRI/56/660	Millers Ranch, Santa Cruz, CA	1000
R/55/530	Kaingaroa, NZ	

1971 Seed Source test

seedlot	provenance
HO/68/620	Deadwood, OR
HO/68/621	Bandon, OR
HO/68/622	Langlois, OR
HO/68/631	Pecwan, CA
HO/68/632	Pecwan, CA
HO/68/627	Tahkenitch, OR
FRI/69/1914	Cpt 1134, Kaingaroa, NZ
FRI/69/1915	Cpts 567, 632, Kaingaroa, NZ
FRI/69/1919	Cpt 1279, Kaingaroa, NZ (Seedstand R/B17)
R69/839	Kaingaroa bulk collection, NZ
NM69/769	Cpt 73, 84, 85, 98 Golden Downs, NZ
C66/525	Cpt 19A, Hanmer, NZ
C69/593	Cpt 12, Ashley NZ
C69/589	Coalgate (Watsons Block) NZ
S67/919	Queenstown
S67/939	Wanaka
S67/918	Naseby

1974 seed source test

seedlot	provenance
C69/593	Cpt 12 Ashley Forest, NZ
HO68/621	Bandon, OR
HO72/774	Korbel, CA
NM69/769	Cpts 73, 84, 85, 89 Golden Downs, NZ
R69/839	Kaingaroa bulk, NZ
FRI72/1937	Cpt 1103, Kaingaroa, NZ

Appendix 3.

COMPOSITION OF DOUGLAS FIR ARCHIVE, WAIKUKU, 1993

SEEDLOT	# CLONES	# RAMETS	PROVENANCE
Seed Stand	8	139	NZ, Ashley Seed stand (ex Oregon)
282	7	132	Washington, Wiskah
401	4	66	NZ, Dusky forest
494	6	74	Washington, Granite Falls
517	4	50	Washington, Snoqualmie
518	10	148	Washington, Olympic
523	5	63	Oregon, Siuslaw N.F.
580	7	134	Oregon, North Bend, Coos County
584	6	102	Oregon, Olny, Clatsop County
593	3	46	NZ, Ashley
621	3	43	Oregon, Bandon
622	2	42	Oregon, Langlois
627	2	35	Oregon, Tahkenitch
631	5	73	Washington, Snohomish county
635	6	115	Oregon, Florence
636	11	177	Oregon, Deadwood
641	7	114	Oregon, Fourmile
642	12	191	California, Hiouichi (Berteleda)
647	10	140	California, Mad River
649	8	117	California, Dehaven
654	16	209	California, Jackson S.F., Ft Bragg
658	11	137	California, Stewart Point
659	8	80	California, Mount Tamalpais
660	12	169	California, Santa Cruz
744	10	67	California, Santa Cruz, Swanton
919	2	40	NZ, Kaingaroa forest
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	185	2703	
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Appendix 4

O. P. seedlots, collected in USA, 1993

Provenance	# seedlots	seed zone	latitude
Los Padres	6	130(CA)	35° 49'
Swanton	3	97(CA)	37° 06'
Cascade ranch	12	97(CA)	37° 08'
SFWD	19	97(CA)	37° 27'
S.P. Taylor	10	96(CA)	38° 02'
Point Reyes	10	96(CA)	38° 04'
Russian R.	10	96(CA)	38° 25'
Fort Ross	10	95(CA)	38° 31'
Gualala	9	95(CA)	38° 47'
Navarro R.	13	95(CA)	39° 11'
Noyo R.	20	94(CA)	39° 25'
Rockport	5	94(CA)	39° 41'
Usal Rd.	1	93(CA)	39° 49'
Arcata (SO)	15	92(CA)	39° 59'
Brookings	7	82 (OR)	42° 06'
Ophir	3	81(OR)	42° 36'
Myrtle Point	9	72(OR)	43° 06'
Coquille	2	71(OR)	43° 13'
Coos Bay	11	71(OR)	43° 20'
Umqua R.	24	71(OR)	43° 34'
Willamette NF	10	262(OR)	43° 50'
Siuslaw NF	21	61(OR)	44° 10'

Appendix 5

Douglas-fir provenance trials

CON	PLOT	SUB	FOREST	COMPART	ABAND	ESTAB	AREA	status	project
AK	257	1	Ahuroa	T.JENKINS		1959	0.87	.	42/ 2
SD	58	8	Berwick	35	1987	1957	4.23	2	42/ 2
SD	58	22	Berwick	35	1976	1959	0.10	2	42/ 2
RO	338	1	FRI Grounds	L.MILE		1961	0.52	.	42/ 2
NN	115	6	Golden Downs	105	1987	1957	5.82	2	42/ 2
NN	122	1	Golden Downs	135		1959	5.19	1	42/ 2
AK	252	1	Glenbervie	50	1983	1959	6.34	.	42/ 2
AK	259	1	Gordonton	A.GOWER	1976	1959	1.34	.	42/ 2
WD	84	4	Granville	3&4	1976	1959	5.05	.	42/ 2
WD	84	4	Granville	4	1976	1959	5.05	.	42/ 2
WN	78	38	Gwavas	55	1987	1967	0.05	.	42/ 2
WN	68	9	Gwavas	52	2003	1957	5.67	1	42/ 2
WN	78	1	Gwavas	55		1959	6.55	1	42/ 2
CY	153	1	Hanmer S.F.P.	48	2002	1957	4.09	1	42/ 2
CY	153	2	Hanmer S.F.P.	48	2002	1959	5.50	1	42/ 2
CY	153	2	Hanmer S.F.P.	52		1959	2.33	1	42/ 2
AK	258	1	Kaipara	M.WALLER	1965	1959	0.15	.	42/ 2
RO	233	9	Kaingaroa	634	1977	1957	1.60	.	42/ 2
RO	233	11	Kaingaroa	634	1977	1959	1.32	.	42/ 2
RO	249	1	Kaingaroa	1149		1957	7.09	1	42/ 2
RO	249	9	Kaingaroa	1149		1959	4.96	1	42/ 2
RO	948	0	Kaingaroa	1346		1967	0.34	2	42/ 2
WN	74	3	Karioi	60	1975	1957	0.34	2	42/ 2
AK	255	1	Maramarua	31		1959	2.19	1	42/ 2
RO	311	1	Patunamu	18	1979	1959	2.05	.	42/ 2
RO	248	1	Patunamu	4	1979	1957	1.41	.	42/ 2
RO	310	0	Kinleith	Rapanui		1959	3.40	1	42/ 2
SD	233	1	Rankleburn	531	1976	1960	0.44	.	42/ 2
SD	231	15	Rankleburn	524		1959	6.55	1	42/ 2
RO	247	1	Rotoehu	46		1957	0.50	2	42/ 2
RO	247	3	Rotoehu	46		1959	0.97	2	42/ 2
AK	253	1	Waitangi	38	1975	1959	1.89	.	42/ 2
RO	302	4	Whakarewarewa	12	1979	1958	0.23	.	42/ 2
AK	256	1	Warkworth	P.WECH	1976	1959	1.37	.	42/ 2
AK	254	1	Whangapoua	9	1972	1959	2.08	.	42/ 2
AK	251	1	Woodhill	114	1971	1959	1.94	.	42/ 2
CY	165	0	Ashley	338		1971	1.08	1	42/ 5
NN	253	0	Golden Downs	65		1971	1.08	2	42/ 5
NN	327	0	Golden Downs	48		1974	0.36	2	42/ 5
CY	166	0	Geraldine	206 Kakahu		1971	1.08	1	42/ 5
RO	388	5	Kaingaroa	1038	1979	1974	0.36	.	42/ 5
RO	944	20	Kaingaroa	1350	1988	1974	0.36	2	42/ 5
SD	229	1	Naseby	20	1976	1971	1.08	.	42/ 5
AK	855	0	Pureora	305		1971	0.86	2	42/ 5
SD	412	0	Rankleburn	10	1987	1974	0.36	2	42/ 5
SD	230	0	Rankleburn	509	1987	1971	1.08	2	42/ 5
RO	908	1	Waimihia	784		1971	1.08	2	42/ 5
RO	907	0	Whakarewarewa	12		1971	0.97	2	42/ 5

Douglas-fir provenance trials (contd)

CON	PLOT	SUB	FOREST	COMPART	ABAND	ESTAB	AREA	status	project
FR	281	1	Golden Downs	247		1996	1.68		42/15
FR	281	2	Tauhara	501		1996	1.68		42/15
FR	281	3	Hanmer	25		1996	1.68		42/15
FR	281	4	Waipori	8		1996	1.68		42/15
FR	281	5	Ribbonwood		1996	1996	1.68		42/15
FR	281	6	Gowan Hills	746		1996	1.15		42/15
FR	281	7	Beaumont	27		1996	1.15		42/15

Douglas-fir progeny trials

CON	PLOT	SUB	FOREST	COMPART	ABAND	ESTAB	AREA	status	project
NN	256	0	Golden Downs	64		1972	2.88		42/ 6
SD	229	4	Naseby	20	1976	1971	1.73		42/ 6
SD	245	0	Rankleburn	509	1987	1972	2.29		42/ 6
RO	908	2	Waimihia	784		1973	5.76		42/ 6
RO	1014	0	Whakarewarewa	21	1987	1972	4.61		42/ 6
FR	280	1	Golden Downs	114		1996	6.80		42/14
FR	280	2	Gowan Hills	740		1996	6.80		42/14
FR	280	3	Kaingaroa	1322		1996	6.80		42/14
FR	375		Beaumont	602		1999	0.47		42/16
FR	440		West Tapanui	205		2002	1.05		42/16

Appendix 6 Douglas-fir plus trees (Superline B) selected and grafted into archives

SERIES	CLONE	PROVENANCE	LATITUDE	FOREST	COMPART	SDLT	FIELD#
888	401	Ca. Mad River	40.92	Kaingaroa	1149	647	401
888	402	Ca. Berteleda	41.80	Kaingaroa	1149	642	402
888	403	Or. Deadwood	44.10	Kaingaroa	1149	636	403
888	404	Or. Coos Bay	43.42	Kaingaroa	1149	580	404
888	405	Or. Fourmile	43.03	Kaingaroa	1149	641	405
888	406	Ca. Stewart Point	38.65	Kaingaroa	1149	658	406
888	407	Ca. Berteleda	41.80	Kaingaroa	1149	642	407
888	408	Wa. Snohomish	48.25	Kaingaroa	1149	631	408
888	409	Or. Florence	43.97	Kaingaroa	1149	635	409
888	410	Ca. Dehaven	39.60	Kaingaroa	1149	649	410
888	411	Or. Deadwood	44.10	Kaingaroa	1149	636	411
888	412	Ca. Santa Cruz	37.08	Kaingaroa	1149	660	412
888	413	Ca. Dehaven	39.60	Kaingaroa	1149	649	413
888	414	Or. Olny	46.08	Kaingaroa	1149	584	414
888	415	Ca. Santa Cruz	37.08	Kaingaroa	1149	660	415
888	416	Ca. Berteleda	41.80	Kaingaroa	1149	642	416
888	417	Ca. Mt. Tamalpais	37.88	Kaingaroa	1149	659	417
888	418	Ca. Mt. Tamalpais	37.88	Kaingaroa	1149	659	418
888	419	Ca. Stewart Point	38.65	Kaingaroa	1149	658	419
888	420	Ca. Fort Bragg	39.35	Kaingaroa	1149	654	420
888	421	Wa. Olympic	47.08	Kaingaroa	1149	518	421
888	422	Wa. Snoqualmie	47.00	Kaingaroa	1149	517	422
888	423	Wa. Wiskah	47.10	Kaingaroa	1149	282	423
888	424	Wa. Granite Falls	48.08	Kaingaroa	1149	494	424
888	425	Or. Siuslaw	44.00	Kaingaroa	1149	523	425
888	426	Wa. Olympic	47.08	Kaingaroa	1149	518	426
888	427	Wa. Olympic	47.08	Kaingaroa	1149	518	427
888	428	Wa. Granite Falls	48.08	Kaingaroa	1149	494	428
888	429	Or. Siuslaw	44.00	Kaingaroa	1149	523	429
888	430	Ca. Fort Bragg	39.35	Rotoehu	55	654	430
888	431	Ca. Fort Bragg	39.35	Rotoehu	55	654	431
888	432	Ca. Fort Bragg	39.35	Rotoehu	55	654	432
888	433	Ca. Fort Bragg	39.35	Rotoehu	55	654	433
888	434	Ca. Fort Bragg	39.35	Rotoehu	55	654	434
888	435	Ca. Santa Cruz	37.12	Rotoehu	88	744	435
888	436	Ca. Santa Cruz	37.12	Rotoehu	88	744	436
888	437	Ca. Santa Cruz	37.12	Rotoehu	88	744	437
888	438	Ca. Santa Cruz	37.12	Rotoehu	88	744	438
888	439	Ca. Santa Cruz	37.12	Rotoehu	88	744	439
888	440	Ca. Santa Cruz	37.12	Rotoehu	88	744	440
888	441	Ca. Santa Cruz	37.12	Rotoehu	88	744	441
888	442	Ca. Santa Cruz	37.12	Rotoehu	88	744	442
888	443	Ca. Santa Cruz	37.12	Rotoehu	88	744	443
888	444	Ca. Santa Cruz	37.12	Rotoehu	88	744	444
888	445	Ca. Fort Bragg	39.35	Gwavas	55	654	445
888	446	Ca. Mt. Tamalpais	37.88	Gwavas	55	659	446
888	447	Wa. Snohomish	48.25	Gwavas	55	631	447
888	448	Or. Florence	43.97	Gwavas	55	635	448
888	449	Or. Deadwood	44.10	Gwavas	55	636	449
888	450	Ca. Berteleda	41.80	Gwavas	55	642	450
888	451	Ca. Stewart Point	38.65	Gwavas	55	658	451
888	452	Ca. Santa Cruz	37.08	Gwavas	55	660	452
888	453	Ca. Berteleda	41.80	Gwavas	55	642	453
888	454	Or. Coos Bay	43.42	Gwavas	55	580	454
888	455	Ca. Mad River	40.92	Gwavas	55	647	455
888	456	Or. Coos Bay	43.42	Gwavas	55	580	456
888	457	Ca. Santa Cruz	37.08	Gwavas	55	660	457

Douglas-fir trees selected and grafted into archives (continued)

SERIES	CLONE	PROVENANCE	LATITUDE	FOREST	COMPART	SDLT	FIELD#
888	458	Ca. Fort Bragg	39.35	Gwavas	55	654	458
888	460	Or. Fourmile	43.03	Gwavas	55	641	460
888	461	Or. Florence	43.97	Gwavas	55	635	461
888	464	Or. Olny	46.08	Gwavas	55	584	464
888	465	Wa. Olympic	47.08	Gwavas	52	518	465
888	466	Wa. Olympic	47.08	Gwavas	52	518	466
888	467	Wa. Snoqualmie	47.00	Gwavas	52	517	467
888	468	Wa. Wiskah	47.10	Gwavas	52	282	468
888	469	Wa. Granite Falls	48.08	Gwavas	52	494	469
888	470	NZ Dusky	47.17	Gwavas	52	401	470
888	471	Or. Siuslaw	44.00	Gwavas	52	523	471
888	482	Ca. Mt. Tamalpais	37.88	Kaingaroa	1149	659	482
888	483	Ca. Mt. Tamalpais	37.88	Kaingaroa	1149	659	483
888	484	Ca. Berteleda	41.80	Kaingaroa	1149	642	484
888	485	Ca. Fort Bragg	39.35	Kinleith	Rapanui	654	485
888	486	Ca. Stewart Point	38.65	Kinleith	Rapanui	658	486
888	487	Ca. Santa Cruz	37.08	Kinleith	Rapanui	660	487
888	488	Ca. Mad River	40.92	Kinleith	Rapanui	647	488
888	489	Ca. Santa Cruz	37.08	Kinleith	Rapanui	660	489
888	490	Ca. Stewart Point	38.65	Kinleith	Rapanui	658	490
888	491	Ca. Mad River	40.92	Kinleith	Rapanui	647	491
888	492	Ca. Fort Bragg	39.35	Kinleith	Rapanui	654	492
888	493	Ca. Dehaven	39.60	Kinleith	Rapanui	649	493
888	494	Or. Fourmile	43.03	Kinleith	Rapanui	641	494
888	495	Or. Olny	46.08	Kinleith	Rapanui	584	495
888	496	Ca. Berteleda	41.80	Kinleith	Rapanui	642	496
888	498	Wa. Snohomish	48.25	Kinleith	Rapanui	631	498
888	499	Or. Fourmile	43.03	Kinleith	Rapanui	641	499
888	500	Or. Deadwood	44.10	Kinleith	Rapanui	636	500
889	522	Ca. Dehaven	39.60	Rankleburn	24	649	1
889	523	Ca. Santa Cruz	37.08	Rankleburn	24	660	2
889	524	Ca. Fort Bragg	39.35	Rankleburn	24	654	3
889	525	Ca. Mad River	40.92	Rankleburn	24	647	4
889	526	Ca. Berteleda	41.80	Rankleburn	24	642	5
889	527	Or. Coos Bay	43.42	Rankleburn	24	580	6
889	528	Ca. Fort Bragg	39.35	Rankleburn	24	654	7
889	529	Or. Olny	46.08	Rankleburn	24	584	8
889	530	Or. Fourmile	43.03	Rankleburn	24	641	9
889	531	Or. Florence	43.97	Rankleburn	24	635	10
889	532	Or. Deadwood	44.10	Rankleburn	24	636	11
889	533	Or. Deadwood	44.10	Rankleburn	24	636	12
889	534	Ca. Mad River	40.92	Rankleburn	24	647	13
889	535	Wa. Snohomish	48.25	Rankleburn	24	631	14
889	536	Ca. Santa Cruz	37.08	Rankleburn	24	660	15
889	537	Ca. Berteleda	41.80	Rankleburn	24	642	16
889	538	Ca. Stewart Point	38.65	Rankleburn	24	658	17
889	539	Ca. Fort Bragg	39.35	Rankleburn	24	654	18
889	540	Ca. Santa Cruz	37.08	Rankleburn	24	660	19
889	541	Ca. Mt. Tamalpais	37.88	Rankleburn	24	659	20
889	542	Or. Bandon	43.08	Rankleburn	10	621	
889	543	NZ Ashley	44.00	Rankleburn	10	593	
889	544	NZ Ashley	44.00	Rankleburn	17	593	
889	545	Or. Bandon	43.08	Rankleburn	17	621	
889	546	Or. Langlois	42.95	Rankleburn	17	622	
889	547	Or. Tahkenitch	43.83	Rankleburn	17	627	
889	548	NZ Kaingaroa	47.00	Rankleburn	17	919	

Douglas-fir trees selected and grafted into archives (continued)

SERIES	CLONE	PROVENANCE	LATITUDE	FOREST	COMPART	SDLT	FIELD#
889	554	NZ Ashley	44.00	Mount Thomas	1		1
889	555	NZ Ashley	44.00	Mount Thomas	1		2
889	557	NZ Ashley	44.00	Ashley	149		1
889	558	NZ Ashley	44.00	Ashley	149		2
889	559	NZ Ashley	44.00	Ashley	149		3
889	560	NZ Ashley	44.00	Ashley	149		4
889	561	NZ Ashley	44.00	Ashley	149		5
889	562	Wa. Wiskah	47.10	Hanmer	48	282	1
889	563	Wa. Olympic	47.08	Hanmer	48	518	2
889	564	Wa. Wiskah	47.10	Hanmer	48	282	3
889	565	Wa. Granite Falls	48.08	Hanmer	48	494	4
889	566	NZ Dusky	47.17	Hanmer	48	401	5
889	567	Wa. Olympic	47.08	Hanmer	48	518	6
889	568	Or. Siuslaw	44.00	Hanmer	48	523	7
889	569	Wa. Snoqualmie	47.00	Hanmer	48	517	8
889	570	Wa. Granite Falls	48.08	Hanmer	48	494	9
889	571	Wa. Wiskah	47.10	Hanmer	48	282	10
889	572	NZ Dusky	47.17	Hanmer	48	401	11
889	573	Ca. Mad River	40.92	Hanmer	52	647	1
889	574	Ca. Dehaven	39.60	Hanmer	52	649	2
889	575	Ca. Stewart Point	38.65	Hanmer	52	658	3
889	576	Ca. Santa Cruz	37.08	Hanmer	52	660	4
889	577	Or. Fourmile	43.03	Hanmer	52	641	5
889	578	Or. Deadwood	44.10	Hanmer	52	636	6
889	579	Or. Deadwood	44.10	Hanmer	48	636	7
889	580	Or. Coos Bay	43.42	Hanmer	48	580	8
889	581	Ca. Berteleda	41.80	Hanmer	48	642	9
889	582	Ca. Dehaven	39.60	Hanmer	48	649	10
889	583	Ca. Mad River	40.92	Hanmer	48	647	11
889	584	Or. Florence	43.97	Hanmer	48	635	12
889	585	Ca. Dehaven	39.60	Hanmer	48	649	13
889	586	Ca. Fort Bragg	39.35	Hanmer	48	654	14
889	587	Ca. Santa Cruz	37.08	Hanmer	48	660	15
889	589	Ca. Mt. Tamalpais	37.88	Hanmer	48	659	17
889	590	Or. Deadwood	44.10	Hanmer	48	636	18
889	591	Ca. Stewart Point	38.65	Hanmer	48	658	19
889	592	Or. Olny	46.08	Hanmer	48	584	20
889	593	Wa. Granite Falls	48.08	Golden Downs	105	494	
889	595	Wa. Wiskah	47.10	Golden Downs	105	282	
889	596	Wa. Wiskah	47.10	Golden Downs	105	282	
889	597	Wa. Olympic	47.08	Golden Downs	105	518	
889	598	Wa. Olympic	47.08	Golden Downs	105	518	
889	599	Wa. Olympic	47.08	Golden Downs	105	518	
889	600	Or. Siuslaw	44.00	Golden Downs	105	523	
889	601	Wa. Snoqualmie	47.00	Golden Downs	105	517	
889	602	NZ Dusky	47.17	Golden Downs	105	401	

Douglas-fir trees selected and grafted into archives (continued)

SERIES	CLONE	PROVENANCE	LATITUDE	FOREST	COMPART	SDLT	FIELD#
889	603	Or. Coos Bay	43.42	Golden Downs	135	580	
889	604	Or. Coos Bay	43.42	Golden Downs	135	580	
889	605	Or. Olny	46.08	Golden Downs	135	584	
889	606	Wa. Snohomish	48.25	Golden Downs	135	631	
889	607	Or. Florence	43.97	Golden Downs	135	635	
889	608	Or. Deadwood	44.10	Golden Downs	135	636	
889	609	Or. Deadwood	44.10	Golden Downs	135	636	
889	610	Or. Fourmile	43.03	Golden Downs	135	641	
889	611	Ca. Berteleda	41.80	Golden Downs	135	642	
889	612	Ca. Berteleda	41.80	Golden Downs	135	642	
889	613	Ca. Mad River	40.92	Golden Downs	135	647	
889	614	Ca. Mad River	40.92	Golden Downs	135	647	
889	615	Ca. Dehaven	39.60	Golden Downs	135	649	
889	616	Ca. Fort Bragg	39.35	Golden Downs	135	654	
889	617	Ca. Fort Bragg	39.35	Golden Downs	135	654	
889	618	Ca. Stewart Point	38.65	Golden Downs	135	658	
889	619	Ca. Stewart Point	38.65	Golden Downs	135	658	
889	620	Ca. Stewart Point	38.65	Golden Downs	135	658	
889	621	Ca. Mt. Tamalpais	37.88	Golden Downs	135	659	
889	622	Ca. Santa Cruz	37.08	Golden Downs	135	660	
889	633	NZ Ashley	44.00	Golden Downs	65	593	
889	634	Or. Langlois	42.95	Golden Downs	65	622	
889	635	NZ Kaingaroa	47.00	Golden Downs	65	919	
889	636	Or. Bandon	43.08	Golden Downs	65	621	
889	637	Or. Tahkenitch	43.83	Golden Downs	65	627	
889	639	NZ Ashley	44.00	Eyrewell	Main Race		