# Douglas-fir Research – Part I

*Piers Maclaren*

*This first volume summarises New Zealand Douglas-fir research from 1994 to 2007, mainly by the Douglas-Fir Research Cooperative. The second volume (yet to be written) will deal with the knowledge gathered up to 1994.*

**Photo: Lake Coleridge stand aged 67.** ***Photo: Nick Ledgard***

# CONTENTS

# Background

Douglas-fir is New Zealand’s second most important exotic conifer, although it falls a long way short of radiata pine in terms of area planted. Higher establishment costs and longer rotations (about twice those of radiata pine) have traditionally tended to discourage expansion, as does Swiss needlecast disease[1].

The species has greatest potential in the South Island high country, much of which has been degraded by frequent burning, overstocking by domestic animals, and the introduction of weeds and pests. Now that burning is restricted, there is widespread reversion to woody species. Deliberate planting is one relatively profitable solution to continuing site degradation[2,3]. While radiata pine is unsuitable for such windy, cold and snow-prone sites, Douglas-fir does well in the higher rainfall locations. (Corsican pine is a possibility for drier high-country sites).

Forest plantations in the South Island high country have been limited because of lack of confidence and knowledge, lack of finance, and obstructive local government and other regulations. Despite these negative influences, there has been increasing interest in Douglas-fir[4], although this is mostly by a small number of larger investors. The potential land bank of good Douglas-fir sites in New Zealand is estimated to be more than a million hectares[5].

Although establishment costs are high, suitable land is relatively cheap (at least compared to typical North Island radiata pine sites) and little or no money need be spent on pruning or thinning. The global market is healthy and appears to have a good long-term future[6]. Environmental pressures to protect Douglas-fir forests in North America should restrict supply and keep prices buoyant.

Unlike the French, who prune 25-30% of their recent plantings in pursuit of the appearance market,[7] the tendency in New Zealand has been to concentrate on Douglas-fir’s (superior) structural qualities, including greater stiffness than radiata pine. The trend towards machine-stress grading will differentiate this species and may provide an increased premium over other softwoods.

A short and easily readable summary of the good attributes and future potential of Douglas-fir can be found in the Tree Grower[8].

---

[1] Shelbourne, C. 1994. Douglas fir breeding plan – draft. Coop Proceedings February 1994, pages 10-23.
[2] Ledgard, N. 2003. Coop Proceedings February 2003, field-day notes page 172.
[3] Ledgard, N. 1997. Coop Proceedings February 1997, page 13.
[4] Belton, M. 2000. The current NZ Douglas-fir new planting and investment scene. Coop proceedings February 2000, pages 25-26.
[5] Belton, M. 1998. Coop report 25.
[6] Parish, J. 1999. Douglas-fir establishment – Ernslaw One experience. Coop proceedings February 1999, pages 14-16.
[7] Belton,. 1998. Op.cit.
[8] Knowles, L. and Ledgard, N. 2004. A great future for Douglas-fir? NZ Tree Grower, February 2004, p.15-16.

# Siting Requirements

Where does Douglas-fir grow well, and why? It would be useful to identify regions, and microsites within those regions, where the growth and form of Douglas-fir is superior. Not only would this tell us which parts of New Zealand could most usefully be planted in Douglas-fir, the study may provide insights on the main drivers that promote good growth and form.

**Gordon Baker shows Coop members an excellent Douglas-fir site.** ***Photo: Nick Ledgard***

## *Growth*

Experience has shown that important factors are rainfall, aspect, slope, exposure, and certain soil attributes (eg soil depth, although not necessarily nutrient deficiencies)[9], but these are unlikely to be adequately described by coarse-scale national topographic and climate datasets and models, so additional microsite information may be needed. This work is in progress.

The disadvantages of higher altitudes include wind, snow, frost, and generally lower temperatures for growth. The advantages include a tendency towards higher rainfall. With Douglas-fir there seems to be no upper limit to the benefits of rainfall[10] and

[9] Coop Newsletter No 6. July 2003. Also, Moore, J.; Ledgard, N.; and Knowles, L. 2006. Effects of topographic position on growth and form of Douglas-fir trees. Coop Report 52..

[10] Ledgard, N.; Belton, M. 1985. Exotic trees in the Canterbury High Country. NZ J For Sci **15**(3): 298-323.

models have been made that are sensitive to the precipitation level[11]. This may explain why – in marked contrast to radiata pine – there is only a weak relationship between altitude or latitude and height growth[12], and possibly explains why Douglas-fir is expanding into more southern, higher altitude sites.

Whether high-altitude or not, sites must be relatively sheltered: wind has been shown to be deleterious to growth. The exposure of a site (as measured by TOPEX) has a marked effect on both height and volume growth[13]. Although a simple system, and one that can be estimated remotely from Geographic Information Systems, it is not clear what TOPEX actually measures: it is not solely exposure, because it is also correlated with rainfall and soil moisture[14].

## *Form*

The TOPEX study also concluded with the unsurprising finding that exposure had a negative effect on stem form. The negative effects of altitude on stem straightness and malformation (forking) were supported by the conclusions of a separate study[15].

## *Frost*

Susceptibility to frost depends on the time of year. Douglas-fir is very frost-resistant in the dormant, winter phase but can be quite susceptible when shoots are flushing in late spring. The timing of this depends on both the provenance and location. To avoid risk of such damage, flat land is normally planted in other species, and Douglas-fir is restricted to sites with some degree of air drainage[16].

**Planting trees on the flat is risky. (*Photo: Nick Ledgard)***

[11] Lawrence, M. 1994. Coop Proceedings July 1994, pages 5-11.
[12] Coop Newsletter No 4. Dec 2001.
[13] Moore, J.; and Ledgard, N. 2005. Coop Proceedings Feb 2005, pages 45-48. Also, Moore et al. 2006. Op. cit. (Report 52).
[14] Moore et al 2006. Op. cit. (Report 52).
[15] Low, C.; Shelbourne, T.; Henley, D. 2006. Eight year performance of provenances and New Zealand seed sources of Douglas-fr on hard sites in the South Island. Coop Report 48.
[16] Coop Proceedings Feb 1997. Field Tour Notes. Page 30.

**Devastation to young seedlings after a Christmas frost.**
***(Photo: Nick Ledgard)***

*Wildings*

Douglas-fir is more shade-tolerant than many other conifers and is amongst the more vigorous spreading species[17]. An increased frequency of Douglas-fir wildings may be due to enhanced inoculation with mycorrhizae[18]. Spread can be mitigated by restricting planting in "takeoff" sites, by fertilising and grazing surrounding areas, by planting buffer strips of non-spreading species, and by removal of wildings every 6 years after an initial 18-year period of grace. There is little evidence that Douglas-fir can successfully invade even relatively open beech forest, although wildings are a problem in shrublands and grasslands[19]. A study of Douglas-fir coning and presence of wildings showed that the upper limit for problematic tree spread is about 1000m[20]. It is very unlikely, however, than many commercial plantations would be established at this altitude.

The disapproving attitude of territorial authorities and the Green movement towards wildings is described in one report[21]. It is possible that this issue alone could

[17] Ledgard, N. 1997. Douglas-fir wilding spread in New Zealand. Coop Proceedings Feb 1997, pages 20-23.
[18] Newsletter 7, page 2.
[19] Ledgard, N. 2007. Wilding update. Coop Proceedings Feb 2007, p. 45-56.
[20] Ledgard, N. 1997. The influence of altitude on Douglas-fir cones and wilding presence. Coop Proceedings, June 1997, pages 35-37.
[21] Ledgard, N. 2001. Wilding risk – as seen by territorial authorities and the Green movement. Coop Proceedings Feb 2001, pages 58-60.

make afforestation with Douglas-fir a controlled or discretionary land use. The Coop is fortunate in having the national expert on wildings as its secretary, and a comprehensive report on all issues connected with Douglas-fir wildings has recently been issued[22]. Technical issues dominate Coop deliberations, but land-use decisions are often made for non-technical reasons, such as public perception. For example, there may be RMA objections to a planting programme (whether based on real issues or due to misconception) and these can create very real financial and procedural hurdles. This was addressed in another report[23].

**Queenstown owes much of its attraction to wilding Douglas-fir.** ***(Photo: Nick Ledgard)***

## *Management tips*

Ernslaw One is a major Douglas-fir grower (some 10,000 ha planted) that is widely respected for the quality of its operations. It has provided a summary[24] of practical guidelines, including: the optimum choice of Douglas-fir site, why the company chose to invest in NZ Douglas-fir, the pre-plant operations, the choice of tree stocks, planting and releasing techniques.

---

[22] Ledgard, N. 2006. Douglas-fir wilding spread and mitigation of risk. Coop Report 50.
[23] Ledgard, N. 1998. Environmental issues arising form recent resource consent applications for Douglas-fir plantations. Coop Proceedings Feb 1998 page 18.
[24] Parish, J. 1999. Douglas-fir establishment, Ernslaw One experience. Coop Proceedings Feb 1999, pages 14-16.


**Queenstown area before wilding D-fir** **Queenstown area after wilding D-fir.**
***(Photos: Nick Ledgard)***

*So where in NZ is the best place to grow Douglas-fir?*

Douglas-fir will grow best on sheltered sites; where the trees do not experience moisture stress in summer; where there is adequate slope to inhibit frost; and which are not too humid to favour Swiss Needle Cast (SNC), yet are relatively warm, especially during the day in summer. To reduce risk of wilding spread, take-off sites should not be planted, and areas downwind of the plantings should be fertilised and grazed. Preferably, there should also be an absence of woody competitors such as broom and gorse.

The temperature criterion may cause some surprise: we know that radiata pine height growth is quite sensitive to temperature but Douglas-fir less so[25] (eg there are marked SI trends for radiata in Kaingaroa Forest from the warm north to the cold south, but no great difference with Douglas-fir). A regression study of Site Index (ie height growth) and SBAP (ie diameter growth) for Douglas-fir showed that there was slightly better height growth in the warmer, low altitude areas, but no discernible diameter trends across the country[26].

It is well known that Douglas-fir is a cool temperate species, and in warmer and wetter areas incurs Swiss Needle Cast Disease. For example, the tree is a rarity north of Hamilton. Yet according to the Lookup Table in the Calculator, except for a few plots in Otago, Kinleith (in south Waikato) is one of the best sites for volume growth (500 Index of 25.5). Another surprising outcome of the Lookup Table is the superlative growth at Arrowtown (500 Index of 31.5) There may be a supply of groundwater on that location, ensuring that there is never a moisture deficit, but nevertheless the Arrowtown climate is quite harsh by New Zealand standards. The two contrasting sites (Kinleith and Arrowtown) may tell us that microsite is all-important, and broad-brush regional differences are not critical. More work is obviously required on this topic.

[25] Van der Colff, M. and Knowles, L. 2002. New set of height/age curves for Douglas-fir in New Zealand. Coop Proceedings, Feb 2002, pages 30-32.
[26] Jung, Su-Young 2003. Influence of site factors on growth of Douglas-fir in NZ. Coop Proceedings Feb 2003, pages 14-22.

# Tree Breeding

The history of Douglas-fir breeding in New Zealand was reviewed by Shelbourne and Low in various reports[27]. Second only to radiata pine, there has been a huge effort into developing this species, and the topic has (arguably) used more Coop resources than any other.

The first step in any breeding programme is to examine the full spectrum of both the natural and introduced populations so that the base of the "breeding pyramid" is as broad as possible, ensuring that all likely winners are captured. The natural range of Douglas-fir is immense and extends from British Columbia to Mexico, but the commercial variety is restricted to within a few hundred kilometres of the western seaboard – albeit across three States. The coastal "fog-belt" provenances – particular at the southern end of the natural range – provide the closest approximation to NZ's maritime climate, and the best offspring. New Zealand scientists have managed to collect a good cross-section of seed from most of these sites and have now established a breeding population of about 400 trees. Provenance trials were established in 1957, 1959, 1972 and 1974 and a further seed collection from promising populations took place in 1993.[28]

A 14-year gap in the breeding programme followed the discovery that stands of Washington State origin (ie almost all Douglas-fir planted in New Zealand prior to 1970) were inferior, and the realisation that the long-term breeding population needed a more substantial base. This has now been rectified by the 1993 collection of seed from a range of good provenances[29].

There was also an unfortunate and over-ambitious venture into a control-pollinated orchard at Waikuku, which does not have a particularly favourable microclimate for Douglas-fir growth and seed production. Control-pollination is more effective but open-pollination is cheaper. Current needs are for progeny testing of open-pollinated seed to provide "breeding values" for selecting seed-orchard clones, and also the development of seed orchards to supply the improved seed.

There is a new emphasis on wood stiffness as a new breeding criterion: selection has traditionally focussed on DBH, stem straightness, absence of forking and ramicorns, and dense, deep crowns with light flat-angled branching. Recent work[30] shows high variability in stiffness between Douglas-fir trees, most of which is unrelated to provenance, and this discovery signals that improved breeds could enhance the yield of

---

[27] Shelbourne, T. and Low, C. 2004. A revised breeding strategy for Douglas-fir in New Zealand. Coop Report 39.
[28] Low, C.; Shelbourne, T.; and Henley, D. 2006. Eight year performance of provenances and New Zealand seed sources of Douglas-fir on hard sites in the South Island. Coop Report 49.
[29] Low, C. and Miller, M. 1994. Selection and seed collection for the NZ breeding population of Douglas-fir from stands in California and Oregon. Coop Report 3.
[30] Knowles, L.; Hansen, L.; Downes. G.; Kimberley, M.; Gaunt, D.: Lee J.; and Roper, J., 2003. Modelling within-tree and between-tree variation in Douglas-fir wood and lumber properties. Proc. IUFRO All Division 5 Conference, Rotorua, NZ. 11-15 March, 2003

premium structural grades in future crops. Although sonic velocity is moderately heritable there is a negative correlation with diameter, therefore care needs to be taken to ensure that diameter growth is not compromised in future selections[31].

**Coop members admire a young seed orchard at Gresson's Road, North Canterbury.**
***(Photo Nick Ledgard)***

## *Breeding plans*

Breeding plans for Douglas-fir were initiated in 1970, reviewed in 1988, and formalised in 1995[32]. A detailed plan for controlled pollination was published in 1996[33], and a revised strategy was issued in 2004[34]. The science of tree breeding is highly complex and specialised, and cannot easily be simplified without distortion, but a few factors might be mentioned. There are three "superlines": one from US Coastal fogbelt populations, a first-generation NZ superline comprising material mainly from provenance trials and seed stands, and a second-generation NZ landrace mainly of Fort Bragg origin. Within each superline, there are a number of sublines. In order to minimise inbreeding while maximising hybrid vigour, it is desirable to cross within sublines and to create a production population from out-crossing between sublines.

The discovery of pine pitch canker on imported Douglas-fir material in November 2003 (from a location that was believed to outside the infection area) has altered the situation somewhat. New Zealand must become self sufficient in seed production, and no reliance should be placed on new introductions from the US fogbelt superline.

## *Growth rate*

Without doubt, the northern Californian and southern Oregon "fog-belt" provenances are the best performers in terms of growth rates, at least on the warmer NZ sites. On a range of such sites (Tokoroa, Kaingaroa, Gwavas, Golden Downs and Hanmer) the top performers have an average growth rate[35] of 20-25 $m^3$/ha/year – rivalling radiata pine – and even reaching 37 $m^3$/ha/year at Tokoroa[36]. Although there is a

[31] Dungey, H.; Low, C.; Gea, L. and Lee, J. 2007. Coop Report 58.
[32] Shelbourne, T. 1995. Douglas-fir breeding plan. Coop report No. 12.
[33] Low, C. 1996. Control pollination of NZ Douglas-fir clones for GCA testing and breeding population establishment. Coop Report 18.
[34] Shelbourne, T. and Low, C. 2004. *Op. cit.* (Report 39).
[35] Growth rate as defined by the 500 Index.
[36] Coop Newsletter No 3, July 2001.

tendency for the faster growing trees to come from warmer provenances – ie growth improves with decreasing latitude and altitude of the original trees[37] – the correlation is not exact. For example, the very warmest provenance in California (Los Padres) is distinctly inferior.

From the 1959 provenance trials, the exact provenances that provide the best volume growth at a stand (rather than an individual tree) level were identified[38], and categorised according to whether their volume growth is a result of superior height or basal area. The top ten performers average 32% increase in yield over the Kaingaroa seedlot of Washington origin, and without exception were from coastal locations in California or southern Oregon. Their superiority was best on the best sites (such as Gwavas, with 55% better volume MAI).

A similar examination of the 1996 trials[39] showed that height growth was best for provenances from around latitude 39° and of Fort Bragg origin but the best provenances overall (ie combining scores for height, straightness and needle retention) appear to be those from Mendocino County in California, especially from Fort Ross and Navarro River.

[37] McInnes, I. 1998. The effect of altitude and latitude in North American Douglas-fir seed sources on basal area, volume and height in New Zealand. Coop Proceedings Feb 1998, pages 9-16.

[38] Kimberley, M. and Knowles, L. 2002. Effect of provenance on growth and yield of Douglas-fir at the stand level. Coop Proceedings Feb 2002, pages 9-21.

Also, Kimberley, M. and Knowles, L. 2007. The 1959 Provenance trials – results to age 47 years. Coop Report 56.

[39] Low, C. 2001. Measurement and analysis of the 1996 Douglas-fir progeny and seed source trials. Coop Proceedings Feb 2001, pages 5-17. Also: Low, C.; Ledgard, N.; Shelbourne, T. 2002. Early growth and form of coastal provenances and progenies of Douglas-fir at three sites in New Zealand. Coop Report 28.

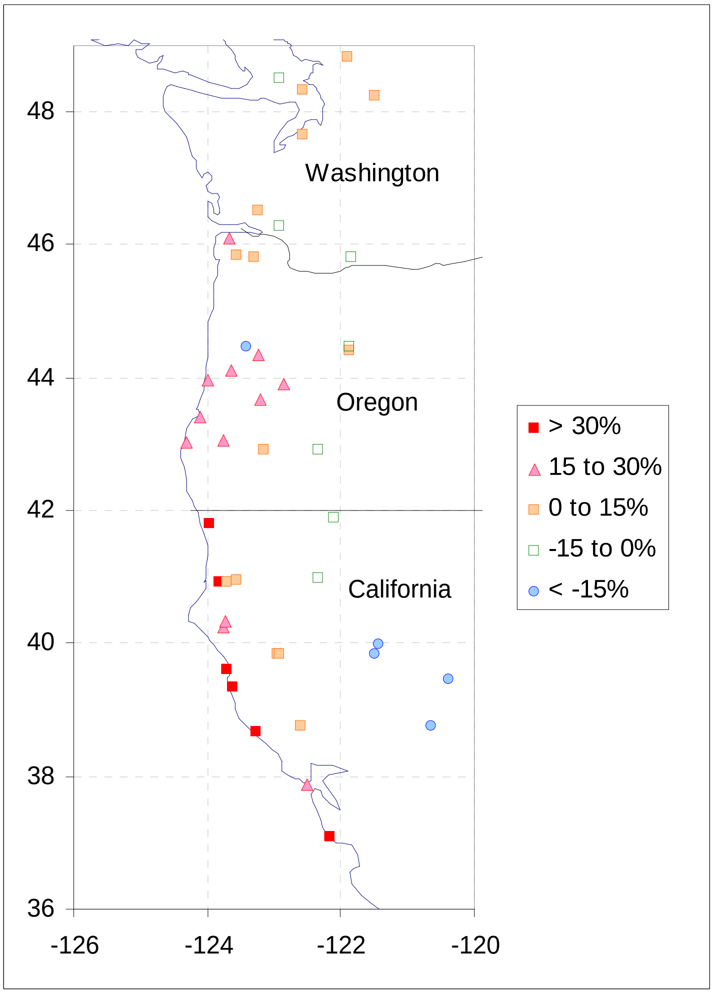



**Fig. 1. Volume MAI gain of each provenance over the Control Seedlot, averaged across all trials, against provenance origin. (*Source: Coop Report 56, Fig 6.*)**

## *Hard sites*

What about harsher conditions such as exposed, snow-prone higher-altitude sites in Southland? Stem malformations in such locations are so common that they mask any effect of provenance, but it seems that Californian stock is as hardy as material from further north (Oregon, and even Washington) and growth rate is just as good[40].

An unseasonal frost (25th November 1998) allowed a comparison of the frost-resistance of different seedlots[41]. There were marked differences between seedlots, but the reasons for this are not clear, except that there is a weak relationship with early flushing. Latitude of the provenance is not correlated with frost damage score, indicating that proximity to the coast may be more important than latitude. Indeed, many fast-

---

[40] Low, C.; Shelbourne, T.; and Henley, D. 2006. Eight year performance of provenances and New Zealand seed sources of Douglas-fir on hard sites in the South Island. Coop Report 49.

[41] Low, C.; and Miller, M. 2000. Frost damage in Douglas-fir provenances at age two years at Waipori Forest (Dunedin). Coop Report 26.

growing Californian provenances showed low frost damage even at Gowan Hills (a cold Southland site).

### *Bark thickness*

Some Californian provenances have noticeably thicker and more deeply furrowed bark than others. The more southerly provenances tend to have greater bark thickness, which could give misleading results if DBH is used to compare growth rates with the same volume function[42], or if the proportion of bark is required for some other purpose. Knowledge of the original latitude of the seed has enabled a volume-correction factor to be constructed to take account of bark thickness. Report 56 shows a smooth curve showing the relationship between the volume adjustment and latitude of the provenance.

### *SNC resistance*

Provenances from the southern end of the natural range tend to be most susceptible to Swiss Needlecast Disease[43]. New Zealand seed sources are most resistant of all, by a small margin. Although trees do not vary in their level of infection, there is considerable difference in their ability to retain foliage after becoming infected[44]. Families differ significantly in their resistance, and heritability of this trait is in the low to moderate range[45].

### *Stiffness*

Heritability estimates of stiffness have been demonstrated as moderate to high on all sites tested[46]. Indeed, the Modulus of Elasticity (MoE) had larger heritabilities than growth traits, and it seems that half the observed variability in stiffness is under genetic control. There is a difference in stiffness between trees as a result of their geographical origin, and the choice of families is important. Having said that, larger differences can be found within stands than between them[47], promising that selection for this trait – even assuming a certain provenance – could pay rich dividends.

Stiffness is a function of both density and microfibril angle (MFA), but of these two factors only density is easy and cheap to measure using current techniques. It seems that MFA explains a lot of the variation in stiffness that occurs within an individual tree (eg in the wood from pith to bark) but density is the best determinant of variation between trees[48]. Therefore, for breeding purposes it may be adequate just to measure breast-height outerwood density as a selection criterion. On the other hand, prediction of

---

[42] McConnon, H. and Knowles, L. 2003. The effect of provenance on bark thickness of Douglas-fir. Coop Report 34. Also: McConnon, H.; Knowles, L.: and Hansen, L. 2004. Provenance affects bark thickness in Douglas fir. NZ J.For.Sci. 34(1): 77-86.
[43] Low, C. 2004. Coop Report 38.
[44] Hood, I. and Kimberley, M. 2003. Susceptibility of Douglas-fir provenance to Swiss Needle Cast Disease in New Zealand. Coop Report No 31.
[45] Johnson, R.; Temel, F.; and Jayawickrama, K. 2003. Genetic studies involving Swiss Needle Cast in Oregon. Coop Proceedings Feb 2003, pages 70-74.
[46] Johnson, R. and Gartner, B. 2006. Variation and heritability of wood quality in Douglas-fir. Coop Proceedings Feb 2006, pages 39-55.
[47] Knowles *et al* 2003, op. cit. Also Johnson and Gartner 2006, op.cit. Also Coop Newsletter No 3, July 2001.
[48] Shelbourne & Low, 2004. Op.cit.

density with a Pilodyn is not that effective[49] despite cost advantages, and is not much better than random selection.

Perhaps a better way of assessing stiffness is to use sonics. The speed that sound waves take to travel between two points either side of breast height can quickly, easily and cheaply be measured with the IML hammer[50], and is a surrogate for stiffness (ie it incorporates the effects of both density and MFA). "Plus trees" that show high sonic velocity while not unduly sacrificing diameter growth have been selected at two initial NZ locations for inclusion in seed orchards[51].

### *Vegetative propagation techniques*

In other species, cuttings are a common way to multiply scarce seed or for use in seed orchards. Weyerhaeuser have produced a million Douglas-fir cuttings per year in the U.S., but the costs were prohibitive due to the need for controlled-climate facilities, and the loss due to plagiotropism (tendency of cuttings to grow as branches, rather than stems). New Zealand researchers have discovered ways to reduce the extent of plagiotropism[52], and have established trials using the new controlled-climate facility in Rotorua. Research into the optimum time to set Douglas-fir cuttings following different stool-bed treatments has, at time of writing, produced inconclusive results[53]. Although the work seems promising for inclusion in the breeding programme, it is unlikely to yield cost-effective rooted cuttings for deployment in production forests. The initial results, however, have prompted further research.

### *Breeding in other countries*

A New Zealand visit to a Douglas-fir breeding facility in Vancouver Island indicated that we already had most of the skills and techniques – back in 1996 – to successfully breed this species[54]. Unusual features of the Canadian operation included a polyhouse, which is covered in winter allowing operations to be carried out in all weathers, and advancing maturation of flowers and pollen by one week. Cones are collected commercially by a suspended "cone rake" flown beneath a helicopter. Canadian experts have also summarised their programs in visits to New Zealand[55], and in general

---

[49] Wedding, A. and Knowles, L. 2003. Application of rapid screening methods for MoE to a seed stand. Coop Proceedings Feb 2003, pages 27-41.

[50] Knowles, L.; Hansen, L.; Wedding, A.; and Downes, G. 2004. Evaluation of non-destructive methods for assessing stiffness of Douglas-fir trees. NZ J. For. Sci. 34(1): 87-101.

[51] Knowles, L. and Lee, J. 2006. Using sonics to identify trees with improved stiffness. Coop Proceedings Feb 2006, pages 57-60.

[52] Faulds, T.; Low, C.; Aimers-Halliday, J.; and Gea. L. 2003. A stool-plant management system for the production of non-plagiotropic cuttings of Douglas-fir. Coop Report 30. See also subsequent reports:
Dibley, M. and Low, C. 2004. Vegetative propagation. Coop Proceedings Feb 2004, pages 66-70.
Gea, L. and Dibley, M. 2005. Vegetative propagation, progress report. Coop Proceedings Feb 2005, page 44.
Low, C. 2006. Douglas-fir vegetative propagation, progress report. Coop Proceedings Feb 2006, pages 17-18.

[53] Low, C. and Dibley, M. 2007. Douglas-fir vegetative propagation – results to 2006. Coop Report 60.

[54] Miller, M. 1996. Douglas-fir breeding at Cowichan Lake Research Station, Vancouver Island, British Columbia. Coop Report 19.

[55] Lee, T. and Crowder, T. 2003. Tree improvement in British Columbia. Coop Proceedings Feb 2003, pages 78-90.

presentations from the Northwest Tree Improvement Cooperative, which includes forest owners from British Columbia right down to California[56]. This coop is about to start second-generation selections.

### *So what is the best seedlot?*

Realised gains of up to 50% in volume and 10.5% in outerwood density can perhaps be obtained by careful selection of outstanding trees within the best provenances[57]. A seed source "ready reckoner" was issued in one report[58] (Table 1 below). It is a provisional estimate only, because it is based on phenotype rather than performance of progeny. Some of the seedlots may not be available because of the new import ban (as a result of possible Pine Pitch Canker).

**TABLE 1** *Seed Source Ready Reckoner*

(1 is desirable, 4 is undesirable)

| Seed Source | | Vigour | Form | | | | SNC | | Flushing time | Frost tolerance | Future avail |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fertile | | Dry | | | | | | |
| | | | Exposed | Sheltered | Exposed | Sheltered | Cool sites | Warm sites | | | |
| Ashley | Mt.Thomas*<br>Eyrewell**<br>Ribbonwood | 3 | 1 | 1 | 1 | 2 | 3 | 2 | 2 | 3 | 3 |
| Beaumont | Blue Mt<br>Blackmount | 2 | 2 | 3 | 2 | 2 | 3 | 2 | 1.5 | 3 | 2 |
| Coronet | Ashley<br>Beaumont | 3 | 2 | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 2 |
| Fort Bragg | Rotoehu<br>Kaingaroa | 4 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 1 |
| Bandon | Rotoaira | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 3 | 1 |
| Swanton | Ngaumu | 4 | 1 | 2 | 2 | 3 | 2 | 1 | 3.5 | 1 | 1 |
| Pomahaka cpt 201 | | 4 | 2 | 3 | 2 | 3 | 4 | 3 | 2.5 | 3 | 2 |
| Kaingaroa strain | | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 1 | 3.5 | 3 |
| Coastal Oregon | | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 |
| Oregon Seed | | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 2 |
| NZ CP seed | | 4 | 3 | 4 | 3 | 3 | 4 | 3 | 3 | 3 | 1 |

* Ashley from Mt Thomas might have some advantage with SNC on warm sites
** Ashley from Eyrewell might have some advantage on form, if sheltered and fertile
*** Coronet from Ashley is not as vigorous and a bit earlier for flushing

[56] Jayawickrama, K. 2003. The Northwest Tree Improvement Cooperative and Douglas-fir genetic improvement. Coop Proceedings Feb 2003, pages 92-120.
[57] Gea, L. 2001. Douglas fir selections: what can we expect? Coop Proceedings Feb 2001, pages 18-21.
[58] Gea, L. 2002. Seed source ready reckoner. Coop Proceedings Feb 2002, page 8.

# Nutrition

## *How important is soil nutrition?*

International reports of nutrition deficiencies in Douglas-fir have included nitrogen, phosphorus, potassium, magnesium, boron, copper, iron and manganese[59]. Having said that, many agriculturally trained experts often do not appreciate that trees differ from most other crops: trees consist almost entirely of carbohydrates derived from water and air, and therefore soils often supply more than adequate nutrients.

It is not surprising, therefore, that a large Douglas-fir nutrition trial (testing N, P, Mg and B) in Kaingaroa Forest failed to detect any significant growth responses to any fertiliser treatment[60]. Similar results were reported from two Nelson trials and from five sites in Otago/Southland (Dusky, Conical Hill, Rankleburn, Beaumont and Berwick)[61]. On the other hand, a Southland trial responded to phosphorus where foliar levels were initially very low (ie 0.6%)[62].

A working assumption might be that fertiliser provides absolutely no benefit on most suitable Douglas-fir sites, but in exceptional cases fertiliser may be required to correct a deficiency or to stimulate growth.

## *How is deficiency determined?*

It is expensive and unnecessary to undertake fertiliser trials on every possible site. Also, soil samples provide measurements that may not accurately translate into plant-available nutrients. Clearly, the most useful predictor of a potential fertiliser response is foliage analysis.

There are difficulties in using foliage analysis with novel species: first, there must be a *sampling protocol* to ensure that measurements are standardised, ie minimally influenced by the time of year or the position of the foliage on the trees. We must know the *critical levels* of nutrients in the foliage sample, so that a growth response is expected if levels are below this figure; and lastly, there should be an estimate of the *quantities of each type of fertiliser* that will raise the foliar concentrations to adequate levels. Some of these factors have been identified in various Coop studies.

## *What sampling protocols have been developed for Douglas-fir?*

Four sites throughout New Zealand were used to note foliar levels of six nutrients for each month of the year. This was done for both primary and secondary foliage[63]. The conclusion was that, for routine monitoring of multi-element nutritional status of Douglas-fir stands, foliage should be collected from second-order branches in the well-lit part of the crown during the months of June or July. A minimum sample of 25 trees (35 is preferable) is necessary to achieve 10% accuracy.

---

[59] Payn, T. and Hunter-Smith, J. 1994. Review of Douglas-fir (*Pseudotsuga menziesii*) nutrition in New Zealand. Coop Report 9.
[60] Graham, D. and Kimberley, M. 2005. FR257 Douglas-fir nutrition trial: foliar nutrient levels and growth effects four years after fertilising. Coop Report 46.
[61] Ledgard, N. 2000. Nutrition research – an update. Coop Proceedings Feb 2000, pages 23-24.
[62] Payn, T. and Hunter-Smith, J. 1994. *Op. cit.* (Report 9).
[63] Graham, D. and Kimberly, M. 2003. Foliage sampling protocols for Douglas-fir in New Zealand. Coop Report 32.

### *What are the critical levels for Douglas-fir?*

Lack of good New Zealand data has forced researchers to use overseas figures[64] that may not be relevant:

| | N % | P % | K % | Mg % | B ppm | Cu ppm |
|---|---|---|---|---|---|---|
| Marginal | 1.3 | 0.10 | 0.45-0.80 | 0.08-0.10 | n.a. | 1-2.6 |
| Adequate | 1.45 | 0.15 | n.a. | 0.12 | 15-20 | 4 |

One Coop report[65] stated, "The results…suggest that critical foliar concentrations for N and P are likely to be lower than some of the published overseas figures". For example, there was no growth response to N at 1.3-1.4, and a healthy level of P was found to be only 0.10.

### *What about boron?*

Phosphorus and boron levels in foliage provided the closest correlation with observed growth[66]. (This does not necessarily indicate, however, that the deficiency *caused* the reduced growth: poor vigour could have been the cause of the deficiencies, or else both observations could have caused by something else).

It is appropriate, therefore, that boron (a cheap fertiliser to apply) has been the focus of research effort. The sinuosity of young trees has been attributed to a lack of boron, although rapid growth combined with wind may be the critical factor[67].

Two long-term boron trials in the South Island have yielded some interim results[68]. There was no noticeable improvement with boron – indeed, even moderate applications (8 kg/ha or 80 kg/ha of ulexite) have reduced growth rates significantly. It has long been known that there is a fine line between levels that cause deficiencies and levels that cause toxicity, but it had not been previously appreciated that Douglas-fir might be even more sensitive to boron toxicity than radiata pine. As for the improvement in form, there was no difference in sinuosity but a significant reduction in broken leaders – but only at a boron application rate that would severely compromise growth. The trial is ongoing, and will eventually look at the role of boron on wood quality.

### *Effect of Douglas-fir on soils*

The effect of afforestation in the South Island high country is poorly publicized, but can be quite spectacular and sometimes beneficial. Productivity of pasture established after harvest of plantations at three sites in the Canterbury high country, for example, was

---

[64] Reuter, D.J. and Robinson, J.B. (eds) 1997. Plant analysis, an interpretation manual. CSIRO Publishing, Australia. Cited in Graham and Kimberley 2003, *op. cit.* (Report 32).
[65] Payne and Hunter-Smith, 1994. *Op.cit.* (Report 9).
[66] Ledgard 2000. *Op.cit.*
[67] Moore, J.; Ledgard, N.; Knowles, L. 2006. Effects of topographic position on growth and form of Douglas-fir trees. Coop Report 52.
[68] Davis, M. 2004. New High Country Douglas-fir boron fertiliser trials. Coop Proceedings Feb 2004, pages 71-73.

found to be 1.4 to 14 times greater than that of adjoining farmland[69]. The effect is through mineralisation of the organic matter in the topsoils, and may also be due to cycling from lower soil horizons, accessible by tree roots but not by pasture. Long-term trials have been established to develop models of nutrient accumulation and recycling[70] and interim reports have been released[71]. There was a marked decline in cations (eg K, Mg and Ca), especially at high stockings, but this was believed to be due to uptake in living biomass and slash. Afforestation with most conifers also causes an increase in acidity, but this over-rated problem can easily be resolved by liming if subsequent land use requires a higher pH.

# Weeds

Without any doubt, successful establishment of Douglas-fir requires control over competing vegetation. It has been estimated that, even using 2/0 Douglas-fir seedlings in parts of Oregon and Washington, without weed control there is only 10-20% survival[72].

The exact causes that make weeds so problematic vary with the site, the size of the planting stock, and the type of weeds. On drier sites, competition for moisture is obviously the major factor – with grass and herbaceous weeds being surprisingly aggressive[73]. On other sites, the main limiting factor seems to be competition for light. In those situations, nutrients or water influence growth strongly only if there is no overtopping vegetation. Beyond a minimum level of herbicide application, planting larger seedlings may be the most cost-effective option. This requires more research.

Height growth is not a good indicator of competitor effects (sacrificing height growth is potential tree "suicide") unlike diameter growth. Where light is the limiting factor, the best way to measure competition levels is a visual estimate of total ground cover for all woody species within a 2.1m radius[74]. It is not clear how the benefits of weed control carry through to rotation age. The benefits may become relatively smaller, be maintained, or become larger. If an analogue with radiata pine thinning is valid, the benefits are likely to be maintained – but only when measured in terms of years, ie the increment of time gained to reach a given tree size.

---

[69] Davis, M. 1997. Impact of afforestation on South Island high country soils. Coop Proceedings Feb 1997, page 19.
[70] Ledgard, N. 1994. Douglas-fir thinning/pruning trial, Ribbonwood Station, Omarama. Progress Report. Coop Proceedings Feb 1994, page 29.
[71] Nordmeyer, A. 1998. Nutrient recycling in Douglas-fir at Ribbonwood. Coop Proceedings Feb 1998, page 17.
[72] Richardson, B. 1994. Effects of interspecific plant competition on Douglas-fir growth and survival. Coop Report 5.
[73] Richardson, B. 1994. Loc. cit.
[74] Richardson, B. 1994. Loc. cit.

**A good weed-free site.** ***(Photo: Nick Ledgard)***

## *What herbicides to use?*

A comprehensive report on herbicides for site preparation and releasing of Douglas-fir was issued in 1994[75]. (Forest nurseries require a totally different range of herbicides, and a separate study). The 1994 report was largely based on overseas literature because there was insufficient NZ information. Differences in soils, climate, growth patterns, etc, could render the results invalid. Furthermore, radiata pine is typically more resistant to herbicides than Douglas-fir, so it would be very dangerous to extrapolate across species.

The exact choice of herbicide will depend on the nature of the target weeds, the time of year, possibly the soil type and moisture status, and whether the herbicide is to be applied pre-planting or after planting. If pre-planting, some herbicides have to be applied sufficiently in advance to allow decomposition of residues.

Safe herbicides that may be applied directly over Douglas-fir include: Gallant, Targa, Gardoprim, and atrazine. Nevertheless there may be mortality, for example if applied during a period of active growth or if a surfactant is added. These herbicides are mainly suitable for grass and herbaceous weeds; therefore more risky chemicals (Velpar, Grazon, Tordon Brushkiller, and Versatill) may need to be carefully applied for spot releasing.

Ernslaw One have summarised their practical experience in two reports[76]. They pre-plant aerial spray with Grazon/Escort for gorse and broom, and with Touchdown/Escort for bracken and honeysuckle. Spot releasing is done with Velpar granules, using Weed-a-metres.

---

[75] Davenhill, N. 1994. Herbicides for controlling weeds in Douglas fir plantations. Coop Report 6.

[76] Parish, J. 1999. Douglas-fir establishment – Ernslaw One experience. Coop Proceedings Feb 1999, pages 14-16. Also, Field Tour Notes, Feb 9-14 2003. Coop Proceedings Feb 2003, page 136.

# Wood properties

## *What are the issues?*

Appearance is not important for New Zealand Douglas-fir timber, but physical properties are critical. We must develop ways to accurately predict, and continue to improve, the structural qualities of the resource to meet the required range of wood products.

## *Why is Douglas-fir different?*

Douglas-fir contrasts with radiata pine, in that there is an abrupt transition between early-wood (laid down in summer) and late-wood (laid down in autumn). The presence of distinctive annual rings makes it less useful for small-dimension products such as mouldings, where the weakness of the early-wood could create difficulties. This may not be a problem overseas, or in situations where there are many rings to the inch, but it does apply in many New Zealand stands. The abrupt transition makes it also problematic to create a smooth surface with a fine finish[77], and to apply varnishes or paints.

In terms of structural characteristics, however, Douglas-fir has some distinct advantages, some of which could relate to the same abrupt transition. Just as laminated or composite structures may combine stiffness or strength with low weight, Douglas-fir has a sandwich structure within each growth ring.

In addition, the stiffness of Douglas-fir (unlike radiata pine) does not decline markedly with corewood, as the following graph (Fig 2) illustrates.

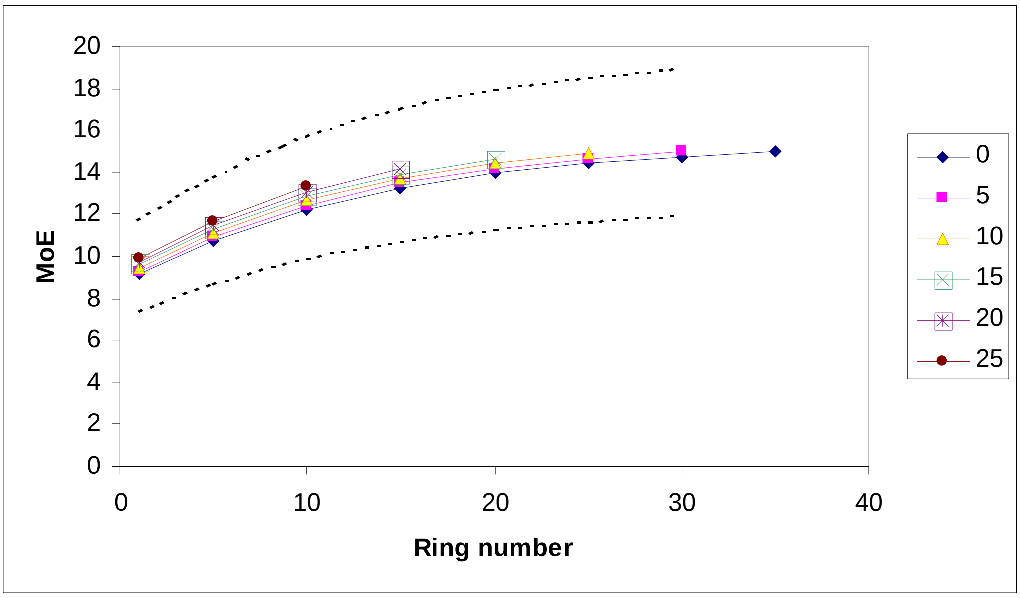


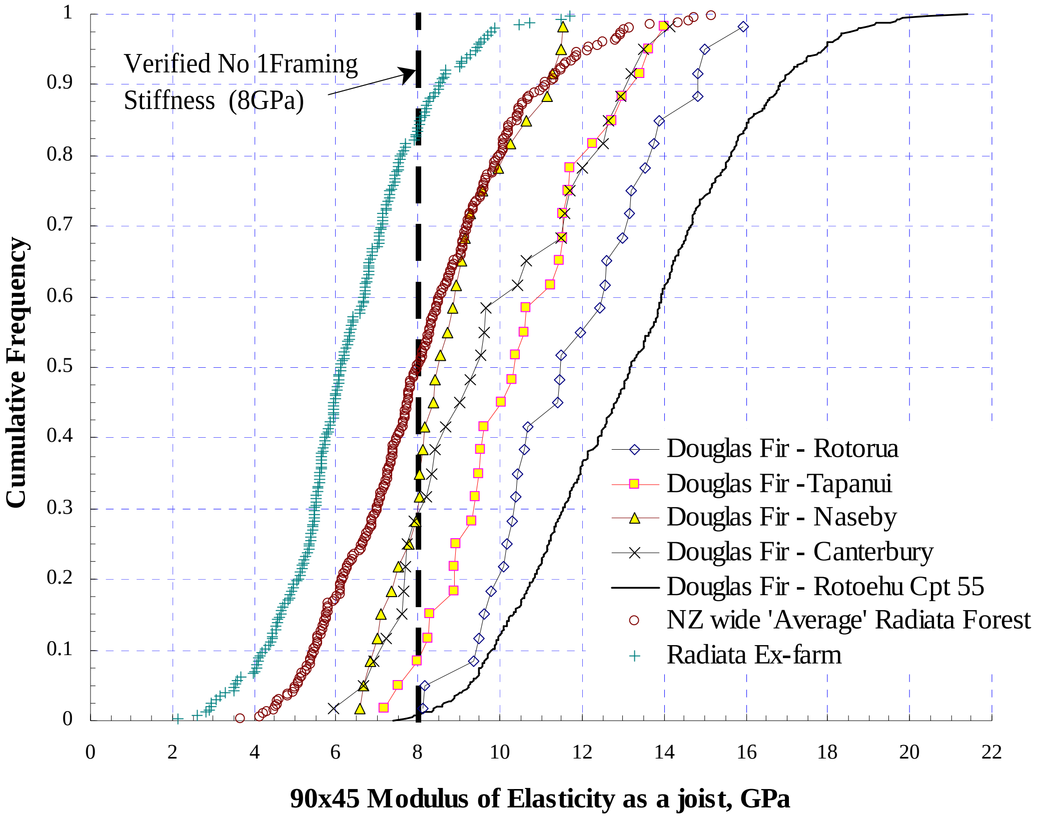

**Fig. 2: Timber MoE versus ring number and height (m) for the mean tree. The dashed lines show the MoE of the best and worst trees at 5 m height.** ***(Source: Coop Report 33, Fig 1.)***

[77] Turner, J. 1995. Clearwood machining properties of NZ Douglas-fir. Coop Report 14.

The major lesson from this graph, and from various conversion studies,[78] is that corewood is not the same problem in Douglas-fir as it is in radiata pine, even though a common (and arguable) definition is "innermost 20 rings" rather than radiata's "innermost 10 rings". The relative superiority of Douglas-fir corewood has implications for: the proportion of harvest-volume that is within-specifications for structural purposes; the utility of thinnings; and the optimum rotation length of clearfellings. It is also becoming increasingly obvious that the need to supply both appearance and structural wood can best be met with different species – at least on some sites.

Continuing this theme, there is a general consensus that the suitability of radiata pine for structural purposes has been declining over the last rotation. This is attributable to: shorter rotations; more intensive silviculture; the move to pasture sites; and the use of '850' genetic stock[79]. In contrast, Douglas-fir structural properties have remained largely unchanged. The trend to machine-stress grading (MSG) will highlight the differences between the two species, and cast doubt on the merits of much of the radiata pine grown for framing in the South Island and on ex-farm sites.

**Fig 3. Bending Stiffness Comparison – Douglas-fir versus radiata pine.** ***(Source Gaunt & Knowles 2004, Fig 1.)***




[78] For example, McConchie, D. 1996. wood properties and sawn timber recovery from Douglas-fir thinnings. Coop Proceedings Feb 1996, pages 13-22.

[79] Gaunt, D. and Knowles, L. 2004. Douglas-fir timber for structural uses – some current issues. Coop proceedings Feb 2004, pages 27-33.

**Unlike much new radiata pine, Douglas-fir is a superb structural timber.**
***(Photo: Nick Ledgard)***

*How important is timber stiffness?*

The most important physical attribute is stiffness – usually this is more critical than strength. (For example, a floor joist or roof truss will bend to unacceptable levels long before it actually breaks). The bending strength of radiata pine is a lot more variable than for Douglas-fir – the wood can be a lot stronger or a lot weaker – but Douglas-fir's stiffness is nearly always substantially greater[80]. Because of this, Douglas-fir commands a premium for structural uses and a higher proportion of mill out-turn will meet new standards based on verification. Indeed, where "average" radiata forest will supply No1 framing (8GPa stiffness) in 50% of the cases and ex-farm sites will meet the specifications only 15% of the time, Douglas-fir will be adequate – or much better than

[80] Gaunt, D. 2006. Changes to structural timber – a Douglas-fir perspective. Coop Proceedings, Feb 2006, pages 61-69.

adequate – in most situations. Douglas-fir is particularly stiff if grown on warmer sites in the North Island, but seems always to be better than radiata pine on the same site.[81]. The comparison of the two species is well illustrated in Fig. 3 (above).

### *How is stiffness measured?*

Stiffness is quantified by the Modulus of Elasticity (MoE) in gigapascals. MoE, as measured in a small sample of wood, is a function of both wood density and microfibril angle – the flatter the angle, the stiffer the wood. Density explains up to 70% of the variation in stiffness, and can be measured simply and with reasonable accuracy with the use of a Pilodyn.[82] Density and microfibril angle together explain 90-95%.[83,84] The (expensive) SilviScan-2 system analyses both density and microfibril angle, and thereby provides the best way to ascertain MoE for *small samples*. But at least four clear specimens per tree, extracted cruciformly, are required to reduce the margin of error per tree to reasonable levels[85].

For *sawn timber*, machine stress grading (MSG) is good at determining the minimum MoE in the material, but poor at grading for strength[86]. MSG is becoming common in New Zealand – at time of writing (April 2007) there are 28 such processors. The most common grades produced from New Zealand Douglas-fir are expected to be MSG8 and MSG10, with MSG12 rare and MSG6 often used for remanufacturing.

For *standing trees*, MoE can be predicted using the bending moment of small clears taken from the same ring around a tree, but there should be at least four in a sample for each tree[87]. Branch index is also important for stiffness[88,89], and an equation has been constructed for predicting the whole-tree MoE from breast-height wood density, microfibril angle, and branch index. This relationship appears to be independent of seed source or stand age, but possibly not for location. The Calculator uses breast-height density and branch index to predict whole-tree MoE, but excludes microfibril angle because Silviscan measurements are expensive and impractical.

An alternative way to assess MoE in standing trees is with sonics. Tools such as the IML hammer measure the velocity of sound in the wood, in the knowledge that MoE equals green density times velocity squared. On *felled logs* (where there is a distinct log length and where there is no interference from branches), tools such as Director[90]

---

[81] Gaunt, D. and Knowles, L. 2004. Op. cit.
[82] McConchie, D. 1996. Op. cit.
[83] Knowles, L.; Kimberley, M.; Hansen, L.; and Downes, G. 2004. Prediction of whole-tree timber MoE in standing Douglas-fir. Coop Proceedings, Feb 2004, pages 36-44.
[84] Knowles, L.; Wichmann-Hansen, L.; and Lee, J. 2004. New generation wood quality study in Douglas-fir. Coop Proceedings, pages 44-51.
[85] Hansen, L.; Knowles, L. and Walford, G. 2004. Residual within-tree variation in stiffness of small clear specimens from *Pinus radiata* and *Pseudotsuga menziesii*. NZ J. For. Sci. 34(2): 206-216.
[86] Gaunt, D. 2006. Op cit.
[87] Wichmann-Hansen, L.; Knowles, R.L.; Walford, G.B. 2004. Estimating individual tree stiffness using small clears. Coop Report no 37.
[88] McConchie, D.; Barbour, J.; McKinley, R.; Kimberley, M.; Gilchrist, K.P; and Cown,D. 1995. Grade recovery and conversion from a Douglas-fir sawing study at Kaingaroa. Coop Rep 13.
[89] Knowles, L.; Kimberley, M.; Hansen, L.; and Downes, G. 2004. Op.cit.
[90] The tool HITMAN is now called Director and is proprietary to FibreGen (NZ) Ltd.

(HITMAN) or SWAT[91] can be employed. The IML hammer provided the best correlation with MoE for standing trees of the methods tested[92], and HITMAN the best for logs. Indeed, when used in combination with other variables (eg density), the correlation with dry timber stiffness is so good that it could provide the standard method for stiffness assessment.

Green timber provides the best estimate of dry timber stiffness, followed by dry timber, logs, and lastly standing trees[93].

### *How can we use our knowledge of stiffness?*

As there is reasonable between-tree variation and heritability of MoE, sonic techniques can be used to select seed trees[94] and for the breeding programme[95]. Selecting only for growth will reduce the MoE by adversely affecting both density and, presumably, microfibril angle. Selecting for density goes some way towards overcoming this problem, but more gain is possible by selecting directly for MoE (for example, by sonics). There is also the possibility of marking trees in normal thinning operations to remove trees with below-average wood properties.

Grade out-turn can also be improved by choosing the stiffest wood at a range of scales: the most suitable stands, trees or logs can be segregated to give superior results. Within a chosen log, sawn timber can be sorted to avoid wood from the juvenile core (not that this is a major issue with Douglas-fir) or to select for outerwood. For example, the butt log of a 50-year old tree is 75% outerwood whereas the third log of a 35-year old tree has 0% outerwood[2]. (This also demonstrates that stands can usefully be grown at longer rotations.)

To summarise, the Coop’s objectives regarding stiffness have been:

- To develop practical methods to measure it, so that the *breeding* programme can be based not only on growth and form, but also on wood quality;
- To identify *situations* (location, regime, breed) where stiffness is likely to be superior, or inferior, to the average case;
- To model stiffness, so that *growers* can respond to market requirements.

### *What about distortion and checking?*

Douglas-fir has the well-deserved reputation of being an easy species to dry, with no appreciable drying degrade.[96,97] In the less common cases where Douglas-fir is used for sarking or decorative panelling, checking can be an issue with wide boards or

---

[91] Produced by Fletcher Challenge Forestry and no longer available.
[92] Knowles, L. and Lee, J. 2005. Progress report on relationships between standing tree and log characteristics, and sawn timber stiffness, for New Zealand-grown Douglas fir. Coop Proceedings, Feb 2005, pages 35-43.
Also, Knowles, L.; Hansen, L.; Wedding, A.; and Downes, G. 2004. Evaluation of non-destructive methods for assessing stiffness of Douglas-fir trees. NZ J. For. Sci. 34(1): 87-101.
[93] Knowles, L.; Lee, J. and Hansen, L. 2007. Assessment of acoustic tools to measure the stiffness of standing trees, logs and timber of New Zealand-grown Douglas-fir. Coop Report 57.
[94] Knowles, L and Lee, J. 2006. Using sonics to identify trees with improved stiffness. Coop Proceedings, Feb 2006, pages 57-60.
[95] Johnson, R. and Gartner, B. 2006. Variation in wood quality of coastal Douglas-fir. Coop Proceedings, Feb 2006, pages 41-55.
[96] McConchie, D. 1996.Op.cit.
[97] Simpson, I.: Haslett, A. 1994. Drying of Douglas-fir clearwood. Coop Report 7.

intergrown knots, but this can be avoided with careful drying-schedules. Juvenile wood is not an issue to the same extent as radiata pine, because spiral grain does not appear to be especially pronounced near the pith, nor is spiral grain a major problem[98].

Microfibril angle is not only useful as an input to calculating MoE; it is also a surrogate for longitudinal shrinkage, depending on the direction of the saw-cut.[99] In other words, reduce the microfibril angle in order to increase stiffness, and there should be a spin-off benefit in decreased longitudinal shrinkage.

For a long time, however, there has been concern about another type of distortion – the tendency of stem leaders in certain locations to grow markedly away from the straight and vertical. North American visitors frequently comment on this – no doubt it is the result of fast growth rate plus a windy environment.

**Twisty leaders are often seen in young Douglas-fir, but are they important?**
***(Photo: Nick Ledgard)***

It is disturbing to see the poor form of such young trees, but – except in rare cases – such sinuosity has only a minor impact on wood quality[100]: it seems that even severely distorted leaders can correct themselves within months[101]. The definitive study

[98] McKinley, R.; McConchie, D.; Lausberg, M.; Gilchrist, K.; and Treloar, C. 1995. Coop Report 10.
[99] Knowles, L.; Wichmann-Hansen, L.; and Lee, J. 2004. Op. cit.
[100] Newsletter 2, December 2000, citing work by Spicer, Garner and Darbyshire in the Canadian Journal of Forest Research.
[101] Newsletter 3, July 2001.

comparing timber recovery with juvenile stem straightness has yet to be undertaken, but with the notable exception of grain deviation caused by large branches and multiple branch whorls, even seemingly severe stem malformation in the juvenile tree may be just a minor issue. Furthermore, there are good heritabilities for straightness so there is a possibility for selection and breeding at a young age[102], although there is a strong negative correlation between stem straightness and height (ie the faster the trees grow, the more sinuous they are likely to be)[103].

### *What of other wood properties?*

Characteristics of the wood from two young (33 year-old) and two older (59 year-old) stands were examined for comparison with North American timber[104]. Given the tendency to harvest in New Zealand at a younger age, there is a greater proportion in this country of inferior corewood, but (as previously mentioned) this is not as severe a problem as with radiata pine.

Whereas heartwood is considered a liability in radiata pine, because it darkens the timber colour and because it is more difficult to treat with preservatives, in Douglas fir it is an asset. Heartwood comprises roughly half of the harvest volume, and has fairly uniform – and very low – moisture content. Indeed, where the moisture content of sapwood can be 150% or more, heartwood might be around 50%. One surprising way to increase heartwood is to grow stands at higher stockings. One twelve-year old stand had almost twice the heartwood area at the higher stockings, and (also surprisingly) the larger-diameter trees had proportionately more heartwood[105].

---

[102] Ledgard, N. and Low, C. 2003. Coop Proceedings Feb 2003, page 23.
[103] Ledgard, N. and Knowles, L. 2001. Coop Proceedings Feb 2001, pages 34-42.
[104] McKinley, R. et al 1995. Op. cit.
[105] Baker, G. and M. Kimberley 1997. Coop Proceedings, February 1997, page 18.

**These Douglas-fir logs in the yard of Starfire Lumber, Oregon, are hundreds of years old. They consist almost entirely of heartwood but are now a rare sight.**
***(Photo: Nick Ledgard)***

### *What about moisture absorption?*

Some woods are like blotting paper and will absorb and transmit large quantities of water from a leaky building or from damp air. Others have water repellent properties. So how does Douglas-fir rate?

There is no doubt that Douglas-fir is less absorbent than radiata pine, but – when totally immersed in water – it nevertheless achieves the 27% moisture content critical for decay within only four days[106]. This is, however, a fairly extreme test. In a more realistic outdoor situation involving natural (Rotorua) weather, the radiata pine reached critical moisture levels within a week, but the Douglas-fir never reached them even after 55 days of exposure[107]. Indeed, in one Coop study radiata pine timber absorbed 3 to 4 times as much water as Douglas-fir after intermittent soaking and drying[108]. It made little difference whether the Douglas-fir was sapwood or heartwood, or where in New Zealand it was grown.

---

[106] Turner, J.; Riley, S.; Haque, N.; and Cown, D. 2005. Comparison of the water absorbency of Douglas-fir and radiata pine framing timber. Coop Report 47.
[107] Hedley, M.; Durbin, G.; Wichmann-Hansen, L.; and Knowles, L. 2004. Comparative moisture uptake of New Zealand grown Douglas-fir and radiata pine structural timber when exposed to rain-wetting. Coop Proceedings February 2004, pages 6-15 and Report 36.
[108] Turner, J.; Penellum, B.; Kimberly, M. and Gaunt, D. 2007. Comparative study of stability between New Zealand grown Douglas-fir and radiata pine structural timber when subjected to moisture cycling. Coop Report 53.

*How readily will Douglas-fir decay?*

Several studies have shown that Douglas-fir is substantially more durable than radiata pine – firstly, because it is harder to reach critical moisture levels (as above), secondly because it is marginally more resistant to pathogenic organisms when it has reached that level[109], and thirdly because it can maintain more cross-sectional decay without structural failure.

*Can Douglas-fir be preservative treated?*

Douglas-fir can be adequately treated up to H1.2 standards using boron diffusion treatment, but LOSP is not a realistic option for Douglas-fir[110]. One commercial process to boron-treat Douglas-fir is Kop-Coat NZ Ltd, which runs the Tru-Core programme[111], and which claims to achieve full sapwood and heartwood penetration.

*Sawing studies*

One Coop sawing study of 195 unpruned logs established a Douglas-fir dataset linking timber grades to log characteristics[112], of which the most important was branch size. Saw patterns had a significant impact on grade recovery. In two other Coop studies, 90 pruned logs in total were sawn in order to provide a similar dataset for pruned logs, and to refine the AUTOSAW model[113,114]. Higher yields were obtained with "live sawing" (ie through-and-through sawing) but higher values were realised with the "cant sawing" method[115].

The major purpose of such studies was to provide regression equations that could predict visual timber grades from log variables such as SED or defect core. This, of course, was to optimise regimes or at least to estimate the intrinsic value of given trees before they were felled. Much of this information is now redundant (as acoustical data has refined timber grades). Furthermore, if a key characteristic of the end product is stiffer – rather than stronger – timber, it may no longer to very useful to categorize log solely in terms of such obvious features as branch size, although this can be used as a visual over-ride after primary classification has been made by means of sonics.

---

[109] Hedley, M. and D.Page 2005. Coop Proceedings February 2005, pages 16-23. Also Hedley M., 2006. Coop Proceedings February 2006, pages 71-82.
[110] Hedley, M. et al. 2004. Op. cit., pages 21-26.
[111] Scott, C. 2005. Coop Proceedings February 2005, pages 7-11.
[112] McConchie, D.; Barbour, J.; McKinley, R.; Kimberley, M.; Gilchrist, K.; and Cown, D. 1995. Grade recovery and conversion from a Douglas-fir sawing study at Kaingaroa. Coop Report 13.
[113] Gatenby, S. and Somerville, A. 1995. Sawing study and AUTOSAW applications on pruned Douglas-fir logs. Coop Report 15.
[114] Todoroki, C. and McInnes, I. 1996. Simulations of timber grade recovery from pruned Douglas-fir logs using AUTOSAW. Coop Report 17.

# Modelling

A considerable amount of research effort has gone into developing computer models for both radiata pine and Douglas-fir. Silviculture, genetic origin, and site interact in complex ways to yield differing outputs. These outputs can take many forms: physical (eg volume by log grade, calendar for scheduling pruning & thinning); financial (eg NPV, IRR); or environmental (eg effect on soil erosion, carbon sequestration, water yield). Computer models are necessary both because there is an infinite combination of inputs, and also because there is a large number of "what if" questions that can be asked. Unless the underlying relationships are extracted and linked, individual trials are merely one-off case-studies – of little general significance. But computer models have the power to analyse all the various interactions simultaneously[116].

## *What is a model?*

The word 'model' is often used loosely. In this report we will use the word 'function' to mean a single equation that describes some specific property of a tree or stand. For example, a *function* may describe how mean top height is predicted. We will use the word 'model' to indicate a more complex simulation that can contain many functions. For example, a growth *model* may predict not only the mean top height, but also basal area and stocking for a particular regime on a particular site. But this information is of no use to a manager unless it is incorporated into a *delivery system* such as FORECASTER or the Douglas-Fir Calculator. With such a delivery system, for example, a manager can derive volumes for each log grade – as defined by the tree characteristics (which involves the use of the growth model, and other models).

## *What delivery systems are available?*

The two main types of forestry "delivery systems" of relevance here occur at the *stand* level and at the *tree* level. Stand models deal with information per hectare – decisions are often made at this scale, or at simple multiples of this scale. Tree-level models contain more detail – such as the size and peculiarities of each particular tree – and are the level at which inventory information is usually obtained. For example, each

[116] To appreciate the infinite range of possibilities, it needs to be understood that *silviculture* involves a combination of initial stocking, final stocking, rotation age, and timing/intensity of thinning and pruning; *genetics* includes the original provenance of the material, the selection that has occurred for various traits, and the homogeneity of the trees (in the extreme, clonal forestry); and even *site* is not best characterized by the simple and misleading term "site index" that has traditionally been used. "Site index" is a measure only of height growth, whereas it is now known that this has almost no correlation with basal area growth at least with radiata pine (Mark Kimberley, Proceedings of Farm and Forest Plantation Management Coop November 2003, p. 48). In addition, there are other site factors that cannot be excluded from a detailed analysis, including slope (affects the cost of harvesting and the possibility of extraction thinnings); nature and extent of weeds and pests (affects growth rate and also early costs); and proximity of essential infrastructure, such as roads and bridges.

tree in a plot may be assessed for height, diameter and malformation, but in stand-level models this information is often pooled and so the detail is lost.

### *a) Stand-level systems*

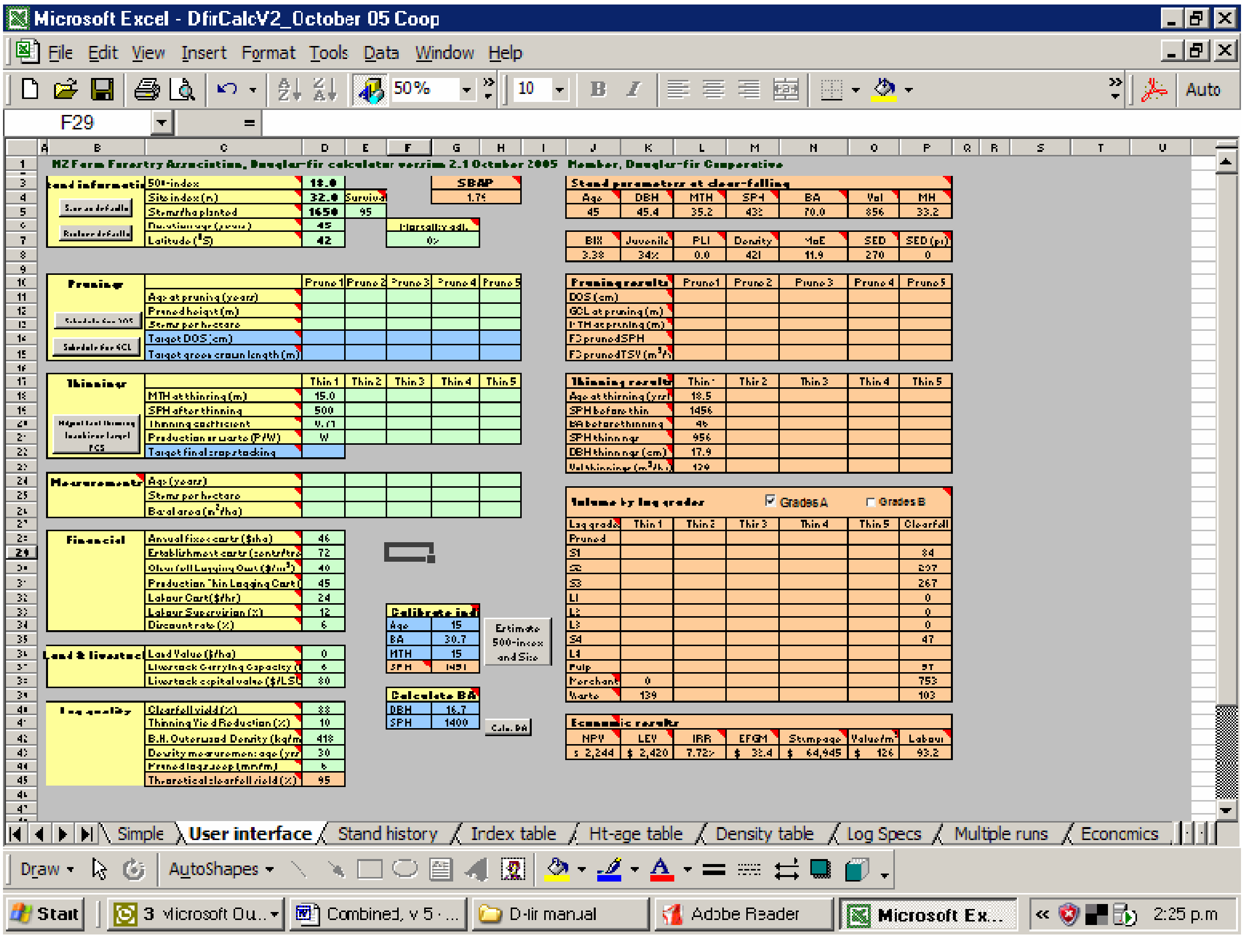
The predominance of radiata pine in the plantation resource has led to sophisticated stand-level systems based primarily on this species. SILMOD has been superseded by STANDPAK, which in turn has (recently) been replaced by FORECASTER. These tools are relatively difficult to use and require knowledge of many inputs. At time of writing, many essential Douglas-fir components have not yet been incorporated into the FORECASTER[117], but there is intention to do so.

There was an obvious case for highly simplified, yet accurate and powerful, tools that would answer the majority of stand-related questions and be more suited to the casual or small-scale user. The radiata and Douglas-fir "Calculators" have been developed in response to that need, and in many ways the Douglas-fir version has pioneered this development – under the aegis of the Douglas-fir Coop, but with support of the MAF Sustainable Farming Fund and the NZ Farm Forestry Association. Being spreadsheet-based models, significant enhancement of the Calculators is unlikely, except for bug-fixing, minor model improvement, and incorporation of certain useful features such as sonic-derived estimates of wood-stiffness. It is important to emphasize that users should not be deceived by the simple appearance of these tools – they are underpinned by complex functions based on robust datasets, and are being subjected to on-going validation.

At time of writing, some 62 functions have been incorporated in the Douglas-fir Calculator, version 2. Some of them have been obtained from previous work in the public domain, but many have been developed by the Douglas-fir Coop specifically to fill gaps in our knowledge and to enable construction of an integrated stand model. The actual equations, including values for the constants, are published in a Coop report[118]. Many of these functions – although initially implemented in the Calculator – could equally well be applied to other software, such as the FORECASTER. The Coop has also issued an updated user's manual of the Douglas-fir Calculator[119].

---

[117] Wakelin, S. 2006. Douglas-fir models in FORECASTER. Coop Proceedings Feb 2006, pages 29-34.
[118] Knowles, L.; Hansen, L.; and Kimberley, M. 2004. Functions contained in the Douglas-fir Calculator version 2. Coop Report 42.
[119] Maclaren, P.; Knowles, L.; and Kimberley, M. 2005. Operating manual for the Green Solution Douglas-fir Calculator. Version 2.1, June 2005.




**The Douglas-fir Calculator. A complex tool, but simple in appearance.**

## b) Tree-level systems

Individual-tree models have the potential to be more useful than stand-level models, because inventory data can be “grown forward”. If, at the start of a projection, this data is merged into stand information, some detailed knowledge of individual trees (eg on stem quality) is lost. The characteristics of individual trees must later be re-created using some distribution function – with inevitable errors.

The best-known delivery systems for inventory projection are MARVL (later, Atlas Cruiser) and YTGen. To facilitate these, the Coop has now developed individual-tree growth models for Douglas-fir similar to the existing ones for radiata pine[120]. They predict diameter reasonably well, but less so in the case of height. Three models have been developed- for the South Island, North Island, and for all of New Zealand. The models are soon to be installed in inventory software such as YTGen. Ongoing validation of these models will then follow.

[120] Van der Colff, M. and Shula, B. 2006. Individual tree-level growth models for Douglas fir in New Zealand. Coop Report 45.

## *Models and functions*

The Coop has developed many models and functions to be used as building blocks of tools such as FORECASTER or the Calculator. They can be categorized into:

1. Diameter and volume growth
2. Ht/age
3. Mortality
4. Branch size
5. Crown Height
6. Wood quality
7. Log grades

Most of the functions are incorporated into the DF NAT growth model (see below), and detailed in Report 42, but are also described separately here.

### *1.* Diameter and volume growth

The Calculator uses the DF NAT stand-level growth model, which comprises two main sub-models: one for height growth and another for basal area growth – involving 21 functions altogether. It is built with growth information from some 1300 sample plots and can be calibrated by simple plot measurements, plus a history of the stand. These inputs calibrate both the site index (ie mean top height at age 40 years) and 500-Index (ie volume increment, see below), which are the two important drivers of the DF NAT model. DF NAT is not yet incorporated into FORECASTER.

Unlike many other available forestry models, DF NAT works throughout New Zealand, has been validated by using data from other countries[121], and can handle the complexities introduced by silvicultural treatments such as thinning and pruning. These operations affect stand volume growth, and also affect the growth rate of different elements within the stand (eg pruned crop and followers). The model can also simulate growth on a monthly basis[122], which may be necessary for scheduling pruning. The latest validation[123] used 242 sample plots and detected a slight excess in "thinning shock" (reduced basal area growth for three years following thinning) relative to the model, but this has since been corrected.

## *What is the 500 Index?*

The *500 Index* is similar to the "300 Index" in radiata pine. It is a measure of volume productivity, and adjusts all regime combinations so that they fit on the same scale and therefore can be compared[124]. Whereas in Europe and North America, the volume of a "fully stocked stand" is used to gauge the productivity of a site, in New

---

[121] Bromley, I. and Knowles, L. 2005. Validation of the New Zealand Douglas-fir growth model (DF NAT) using data from Southwest Germany. Coop Report 43.
[122] McInnes, I. 1994. Monthly basal area growth distribution of Douglas-fir in New Zealand. Coop Report 2.
[123] Knowles, L. and Hansen, L. 2007. Validation of the New Zealand National Douglas-fir Growth Model (DFNAT). Coop Report 54.
[124] Knowles, L. 2005. Development of a productivity index for Douglas-fir. NZ J. Forestry, August 2005, 50(2): 19:22.

Zealand we deliberately thin to allow space for individual trees to expand. We may also choose to prune, in order to enhance the proportion of clearwood. Both these operations have the effect of reducing stand productivity, and therefore allowance must be made for that. "500 Index" is defined as the mean volume increment ($m^3$/ha/yr) of a stand that is planted at around 1650 s/ha, thinned at about age 15 to 500 s/ha, is unpruned, and grown to age 40. The 500 Index can be calculated from knowledge of site index and basal area growth[125].

### *What is the best way to estimate stand volume?*

Using *stand volume equations*, stand volume can be derived from BA and MTH – directly obtainable from actual plot data. But this is merely an estimate based on another estimate: the equations were constructed from the sum of the volume of individual trees using a selected *tree volume* equation. One can appreciate that two foresters could easily disagree on a stand's volume, depending on which stand volume equation was chosen, and which individual-tree volume equation was used to contribute to that stand volume equation.

Individual-tree volume functions are currently being developed using the '3P' system. Tree volume is predicted using the diameter at breast height, the height of the tree and a third – new – component, the diameter of the stem at a point further up the tree. This third component helps to reduce the variability in the "form factor" from tree to tree. In other words, some trees taper less in the middle than others and it pays to measure the extent of the intermediate taper.

The Calculator uses Stand Volume 36[126], based on tree volume function T136 with the philosophy that "one size fits all" and that some imprecision is worthwhile in the cause of simplicity. But a recent Coop report[127] suggests that the simple, robust and time-honoured Beekhuis model is more suitable in the interim, and that *New Formula 1* should eventually supersede the earlier system. There is still debate over whether a simple national function is better than four regional functions, and there is concern over estimates of volume in the upper South Island and at high volume levels. When the '3P' tree-level volume function becomes available throughout the PSP system, it will be necessary to refit a new national stand-level volume function.

### 2. Height/Age functions

The Coop has developed a single stand-level height/age function to supersede the previous eight regional models, which were out-dated and geographically incomplete.[128]. Traditionally, it was often not clear which model to choose – particularly at the regional boundaries – and the selection was sometimes critical. The new model has been validated

---

[125] The equation actually uses Site Basal Area Potential, which is the average BA increment over one rotation for a fully stocked stand. For the equation that links 500 Index to site index and SBAP, see Knowles, L. and L. Hansen. 2004. Application of the New Zealand Douglas-fir silvicultural growth model (DF NAT) to data from the Pacific Northwest. Coop report 41, page 7. Also Knowles, L. 2005. Development of a productivity index for Douglas-fir. Coop report 44. Also published in Knowles, R.L. 2005: "Development of a productivity index for Douglas-fir" *NZ Journal of Forestry 50(2): 19-22*
[126] Knowles, Hansen, and Kimberley, 2004. Op.cit. (Report 42).
[127] Watts, M.; Knowles, L.; and Kimberley, M. 2006. Volume functions for Douglas-fir. Coop Report 48.
[128] Van der Colff, M. and Knowles, L. 2004. Development of new stand-level height-age curves for Douglas-fir in New Zealand. Coop Report 40.

against 869 plots from six regions and while it does not always give better results than regional models, the differences are minimal. It is an obvious choice given the avoidance of confusion in borderline cases (the new model includes a term for latitude) and the simplicity of a single national model.

Individual-tree height functions have also been developed for the South Island, the North Island and for all New Zealand[129].

### 3. Mortality functions

The mortality component of the national stand-level Douglas-fir model DFNAT was for a time a weak link. The new function[130] replaces the 1995 version[131]. It has been shown that Reinecke's globally acknowledged 1933 "self-thinning rule" (which has an upper limit of basal area for a given age) needs to be adjusted for site productivity, ie the 500 Index. More productive sites can carry a higher basal area and volume.

Mortality functions have also been developed at the tree level, with the probability of survival of the individual tree based on stocking and diameter[132].

### 4. Branch functions

Some 36,000 branches from 528 trees at nine sites were measured. There was found to be a very strong relationship between the maximum branch and BIX (the average of the largest branch in each of four quadrants)[133]. The Coop has developed a model to predict branch size in second logs[134], which is a factor of critical importance for estimating volume by log grade. An estimate of branch size in other log-height classes can then be made.

### 5. Crown Length functions

Crown length (per hectare and per tree) is useful for several reasons: it is a driver of stand basal area increment, it is required to compute separate growth trajectories for pruned and unpruned elements, and it determines the extent to which branches have died and have produced bark-encased knots. The Coop has piggybacked on the work of a sister coop (radiata pine Stand Management) to enhance the crown-prediction functions outlined in the very first Douglas-fir coop report[135].

---

[129] Van der Colff, M. and Shula, B. 2004. A prototype of individual tree diameter and height/increment models for Douglas-fir in New Zealand – progress report to February 2004. Coop Proceedings Feb 2004, pages 53-60. Also, Coop Report 45.

[130] Kimberley, M. and Knowles, L. 2007. A new mortality function for New Zealand Douglas-fir. Coop Report 55.

[131] Middlemiss, M. and Knowles, L. 1995. A mortality function for Douglas-fir up to stand age 30 years. Coop Report 11.

[132] Van der Colff, M. and Shula, B. 2005. New Zealand Douglas-fir individual tree level survival model. Coop Proceedings Feb 2005, pages 24-29.

[133] McInnes, I. 1996. Douglas-fir branch study – preliminary results. Coop Proceedings Feb 1996, pages 7-12.

[134] McInnes, I. 1997. An improved function for predicting second-log branch index in Douglas-fir. Coop Proceedings June 1997, pages 26-30.

[135] McInnes, I. 1994. Predicting green crown height in Douglas-fir in New Zealand. Coop Report 1. Superseded by the methodology developed by Turner, J. 1998. Predicting green crown length in radiata pine. Proceedings of Forest & Farm Plantation Management Coop, May 1998, pages 9-24. Also Coop Proceedings Feb 1997, pages 34-37. Also Lee, K-H.; McInnes, I; and Knowles, L. 2001. Allocating basal

## 6. Wood quality functions

For many years now, many external features of logs have been recorded, modelled, and used in the definitions of log grades. Such features include sweep, branch size, stem size, and taper. It is becoming increasingly apparent that these constitute only part of the wood-quality picture – internal characteristics are equally important. Some features of internal wood quality are predictable using standard measurements: namely, the percentage of (inferior) juvenile wood in logs, and the DOS of pruned logs. But others must be specifically measured and modelled.

In the case of Douglas-fir, which is grown mainly for structural purposes, a key characteristic is stiffness: a function of wood density, micro-fibril angle (MFA) and branch size[136]. The problem is that, with present technology, MFA is hard to measure or predict. Because of this difficulty, the model in the Calculator omits this important term, and predicts stiffness entirely on the basis of density and branch size[137], albeit with imprecision. The average whole-tree density is computed from the known relationship between samples of outerwood density taken at a young age and the average tree density at harvest.

Some 35% of the variance in timber stiffness in pieces of Douglas-fir timber occurs between trees, and might be amenable to improvement with a tree-breeding programme. Of this variance, 75% is directly related to clearwood characteristics (ie density and MFA) and 10% to branch diameter. Some 27% of variance is related to the position of the wood within a tree – 90% due to ring age, and the rest due to height[138].

There is a good relationship between sonic velocity in standing trees (as obtained, for example, with an IML electronic hammer) and timber MOE (ie stiffness)[139]. The challenge is to develop models to predict stiffness in each log of a tree from a sonic measurement taken earlier in the rotation, and then to incorporate this knowledge into delivery systems.

The closer measurements of stiffness are made to the end product (timber), then the more accurate the estimate. For example, if we bend a piece of dry 100x50 mm timber (on edge), we obtain its ‘true’ MoE. If we weigh the same piece green (to obtain its green density) and measure the sound velocity using the Director HM200 tool, we get a very similar figure[140]. But if we go back one step and use the DirectorHM200 on logs – without a measure of green density –the correlation with MoE is only about 0.8[141]. If we go back a further step, and use the IML hammer on standing trees, the correlation drops to only 0.6. That said, this relationship is still useful – and better than density alone. Douglas-fir may be different in this respect to radiata pine, where traditional density cores may sometimes be preferred to sonic tools[142].

---

area increment to stand elements in pruned stands of Douglas-fir. Coop Proceedings Feb 2001, pages 52-57.

[136] Knowles, L.; Kimberley, M.; Hansen, L.; and Downs, G. 2004. Coop Proceedings Feb 2004, pages 36-44.

[137] Knowles, L.; Hansen, L.; and Kimberley, M. 2004. Op. cit. (Report 42).

[138] Knowles, L.; Kimberley, M.; Gaunt, D.; Hansen. L.; and Downes, G. 2003. Coop Report 33.

[139] Knowles, L. and Lee, J. 2005. Coop Proceedings Feb 2005, pages 35-43.

[140] MoE= green density x velocity squared.

[141] Knowles, L. and Lee 2005. Op. cit.

[142] Knowles, R. L; Hansen, L. W; Wedding, A; Downes, G. 2004: “Evaluation of non-destructive methods for assessing stiffness of Douglas fir trees”. NZ Journal of Forestry Science 34(1): 87-101.

## 7. Log grade functions

A common fault in some alternative (non-Coop) models is to restrict their predictions to total stem volume, as if this were the desired end result, but it is essential that outputs should be in the form of *volume by log grade*. Specifications for these grades must be flexible, because they vary from buyer to buyer, and change over time, and they must be sufficiently simple and robust to be of practical use on the skid site. Sawing studies can demonstrate how log grades actually translate into timber grades[143].

### *Biomass evaluation & carbon*

The quantity of non-stem biomass (branches, foliage, etc) is useful for: the understanding of nutrient recycling; physiological modelling; determination of ignition temperature and fuel loading for fire research; and lastly for calculation of the capacity of a species to act as a carbon sink or reservoir (ie carbon modelling). A breakdown of biomass components of Douglas-fir from the Coop's trials has been completed but is not yet reported in written form or incorporated into existing models. The superiority of Douglas-fir over radiata pine as a carbon sink is described in one report[144].

### *Continuous cover*

The Coop brokered a review of Continuous Cover forestry as part of a government initiative to devolve sink credits under the Permanent Forest Sink Initiative. The review[145] assessed Continuous Cover forestry with Douglas-fir (other species were evaluated in different programmes), and concluded that it was feasible so long as stockings were kept at very low levels or logging coupes were allowed to reach 0.25 ha or more. No substantial practical benefit (for carbon or for any other purpose) was identified in this politically driven initiative.

### *Some Model Results*

As discussed earlier, the main use of models is to be incorporated in delivery systems, and the main uses of such systems is to: examine silvicultural regimes; schedule silviculture; forecast yield for contractual purposes and for forward planning; predict profitability, cash-flow and forest valuation for the benefit of owners and prospective investors.

Occasionally, however, a good model will throw up results of general interest. One example is the productivity of NZ-grown Douglas-fir. How do growth rates compare with other countries, and do we have a genuine advantage in this respect? This question can be addressed by using the 500 Index, as follows: an analysis of 303 plots from 27 trial installations in the Pacific NorthWest gave a maximum 500 Index of 17.39 $m^3$/ha/yr[146]. This is less than the average for New Zealand of 18.4[147]. In France, "Site

---

[143] Gatenby, S. and Somerville, A. 1995. Sawing study and AUTOSAW applications on pruned Douglas-fir logs. Coop Report 15. Also Knowles, L. 1994. Coop Proceedings July 1994, page 15.
[144] Ledgard, N. and Maclaren, P. 1999. Douglas-fir versus radiata for carbon storage. Coop Proceedings Feb 1999 pages 17-20.
[145] Maclaren, P., Knowles, L., and Ledgard, N. 2006. Continuous-cover forestry with Douglas-fir. Coop Report 51.
[146] Knowles and Hansen, 2004. Op.cit. (Report 41).
[147] Figure taken from the Index tables in the Calculator

Class 1" has increments of 24-26 $m^3$/ha/yr[148], whereas the maximum in New Zealand is recorded as 31.5 at Arrowtown. Productivity in Germany is estimated to be about 15% less than in New Zealand[149].

We can categorically state, therefore, that NZ appears to have a major advantage in growing Douglas-fir relative to other regions – especially compared to the geographical home of this species. In its original territory, a range of pests and diseases may restrict growth[150].

We can also see at a glance which localities have the best height growth, the best basal area growth, and the best volume growth, by examining a "lookup" table[151]. The challenge is to construct a national "productivity map" which links areas of similar productivity, and which can be related to measurable site factors such as rainfall and temperature.

# Pests and diseases

Some 150 arthropods have been recorded from Douglas-fir in New Zealand and a number of others are present overseas but have yet to reach our shores[152]. It is believed that these constitute a low risk to commercial viability of this species, but no guarantee can be given. The fact that NZ plantations are usually thinned – and therefore not under stress, unlike some of their relatives in their natural habitat – offers good protection in many scenarios.

In contrast to arthropod pests, there are a number of fungi that do pose some threat. These include root diseases and decays – the foremost of which is laminated root rot – heart rots, sap rots and needle diseases[153].

## *Swiss Needle Cast Disease (SNC)*

The fungus *Phaeocryptopus gaeumannii* reduces Douglas-fir diameter and height growth by causing chlorosis (yellowing) and premature loss of needles. It was discovered in New Zealand in 1959, and is most detrimental in the warmer and wetter parts of New Zealand. Even in its native range (where trees can be expected to be tolerant of this indigenous fungus) volume growth is estimated to be 22% lower over large areas[154]. The drop in production may be due to a new virulent strain or it may be to changing environmental conditions. A comprehensive description of the disease from the viewpoint of the PNW is available in a Coop publication[155].

---

148 Belton, M. 1998. Britain and France Douglas-fir forestry study tour 1997. Report 25.
149 Bromley, I. and L. Knowles, 2004. Op. cit. (Report 43).
150 Hood, I. 2005. Coop Proceedings Feb 2005, page 68. Also, Kay, N. 2005. Coop Proceedings Feb 2005, pagea 58-68.
151 Knowles, L. and Hansen, L. 2005. Coop Proceedings Feb 2005, pages 32-34.
152 Kay, N. 2005. Coop Proceedings Feb 2005, pages 58-68.
153 Hood, I. 2005. Douglas-fir diseases in the natural Douglas-fir zone. Coop Proceedings Feb 2005, page 53.
154 Douglas-fir Research Coop Newsletter 1.
155 Oregon Department of Forestry, 1998. Forest Health Note – Swiss needle cast of Douglas-fir in coastal western Oregon. Coop Proceedings Feb 2000, pages 28-38.

One early assessment of growth loss in New Zealand showed that gross basal area increment was on average 74% of the pre-SNC records, with extremes being 60% lower[156]. A more recent assessment[157] examined the time from first infection to ultimate growth loss (answer: about 10 years) and estimated the typical loss in log value per hectare at 26%.

Genetic studies of SNC in Oregon[158] suggested that better performing families shed their infected needles, while those severely affected held on to them longer. Infestation was the same between families, but they differed significantly in their degree of needle retention, foliage density and colour. Seedlots from the south of San Francisco have generally poor resistance[159].

A workplan has commenced to look at the occurrence of SNC in New Zealand, in order to explain and predict the regional incidence and impact of this disease under local conditions[160]. Much work is taking place in the Pacific Northwest on this disease, through the SNC Cooperative[161]. Initial results show a similar relationship to that in western Oregon: the abundance of the disease In New Zealand is correlated with August minimum temperature and June average temperature[162].

## *Pitch Canker Disease*

Pine Pitch canker (*Fusarium subglutinans*) is devastating radiata pine in its natural homeland, and threatens New Zealand through imports of either live plants or seeds. As well as many species of pine, its hosts include Douglas-fir[163]. Most of the fungal load is carried on the surface of imported seed and can be easily treated, but some is endophytic – in other words, it is carried internally[164]. Scion wood collected from a Douglas-fir seed orchard in November 2002 was found to be contaminated with the fungus on arrival[165] and has led to a complete ban of imports of any Douglas-fir material.

---

[156] Manley, B. 1985. Growth loss of Douglas fir associated with *Phaeocryptopus* in Kaingaroa Forest. Paper No. 3 in 1985 Douglas fir workshop, reproduced in Coop Proceedings Feb 1994, page 33.

[157] Knowles, L.; Kimberley, M.; and Hood, I. 2001. Swiss needle cast disease of Douglas-fir – impact on growth. Forest Health News, No. 114 Dec 2001. Also, Coop Proceedings Feb 2002, pages 22-24.

[158] Johnson, R.; Temel, F.; and Jayawickrama, K. 2003. Genetic studies involving Swiss needle cast in Oregon. Coop Proceedings Feb 2003, pages 70-76.

[159] Low, C. and Henley, D. 2005. 1996 seed source trials. Coop Proceedings Feb 2005, pages 84-94.

[160] Hood, I. and Stone, J. 2006. Swiss needle cast of Douglas fir – influence of climate and pathogen population structure on disease distribution and incidence. Coop Proceedings Feb 2006, pages 21-25.

[161] Pierson, D. 2003. Industrial Douglas-fir management intentions in Western Washington and Oregon. Coop Proceedings Feb 2003, pages 52-69.

[162] Stone, J.; Hood, I.; Watt, M.: Kerrigan, J. and Ramsfield, T. 2007. Distribution of Swiss Needle Cast in New Zealand in relation to winter temperature. Coop Report 59.

[163] Dick, M. 1994. Forest Health News. Reproduced in Coop Proceedings Feb 1995, pages 31-31.

[164] Dick, M. 1998. Fusarium contamination of Douglas fir seed. Coop Proceedings Feb 1998, pages 26-29.

[165] Vogler, D. 2005. Pitch canker in the Sierra Nevada, and what we are doing about it. Coop Proceedings Feb 2005, pages 54-57.

# Summary

The Douglas-fir Research Coop is not merely a forum for professional researchers, although it does provide a worthwhile means of technology transfer. It is also a place where practitioners can influence the direction of research, provide practical assistance to researchers, and share their experiences during conference intervals and field trips. A worthwhile “bang for the buck” is obtained by pooling industry and government’s research investment, with “freeloading” almost unknown.

The achievements of this small Coop, with only a modest subscription fee, are quite remarkable, as can be seen from the scope and depth of research documented in this report.

The Coop intends to produce a second summary of Douglas-fir knowledge, incorporating all the information obtained (not necessarily by formal techniques) prior to the formation of the Coop in 1994.

*Acknowledgements*

The author is grateful for those who have refereed this report: Charles Etherington, Dennys Guild, Leith Knowles, Charlie Low, Dave Lowry, and Patrick Milne. Leith Knowles also – as would be expected – contributed the initial idea and provided help throughout.

**The rolling terrain in the middle is ideal plantable country.** ***(Photo: Nick Ledgard)***