NEW ZEALAND
FOREST RESEARCH INSTITUTE
LIMITED

FRI BULLETIN NO. 124

INTRODUCED FOREST TREES IN NEW ZEALAND

Recognition, Role, and Seed Source

14. DOUGLAS-FIR

Pseudotsuga menziesii **(Mirbel) Franco**

J.T. MILLER AND F.B. KNOWLES

This FRI bulletin series was compiled for people with an interest in the introduced trees of New Zealand, such as foresters, farm foresters, nurserymen, and students. It includes:

1. *Pinus nigra* Arn. — European black pine
2. *Pinus contorta* Loudon — contorta pine
3. The larches — *Larix decidua* Miller, *Larix kaempferi* (Lambert) Carr., *Larix* x *eurolepis* A. Henry
4. *Pinus mugo* Turra — dwarf mountain pine; *Pinus uncinata* Mirbel — mountain pine
5. *Pinus attenuata* Lemmon — knobcone pine
6. The spruces — *Picea sitchensis* (Bong.) Carrière, *Picea abies* (L.) Karsten, ornamental spruces
7. The silver firs — *Abies* spp.
8. *Pinus pinaster* Aiton — maritime pine
9. The cypresses — *Cupressus* spp.; *Chamaecyparis* spp.
10. Ponderosa and Jeffrey Pines —*Pinus ponderosa* P. Lawson et Lawson, *Pinus jeffreyi* Grev. et Balf.
11. *Eucalyptus nitens* (Deane et Maiden) Maiden
12. Radiata pine — *Pinus radiata* D. Don
13. The redwoods — *Sequoia sempervirens* (D. Don) Endl. — coast redwood, *Sequoiadendron giganteum* (Lindley) J. Buchholz — giant sequoia, and the related ornamental genera *Taxodium* and *Metasequoia*

This bulletin was published with financial assistance from the Foundation of Research, Science and Technology (Contract No. CO 4309), the Agricultural and Marketing Research and Development Trust, Ernslaw One Limited, and the Taupo and Districts Branch of the New Zealand Farm Forestry Association.

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COVER PHOTOGRAPH: Felling of 60-year-old Douglas-fir at Dusky Forest, West Otago.

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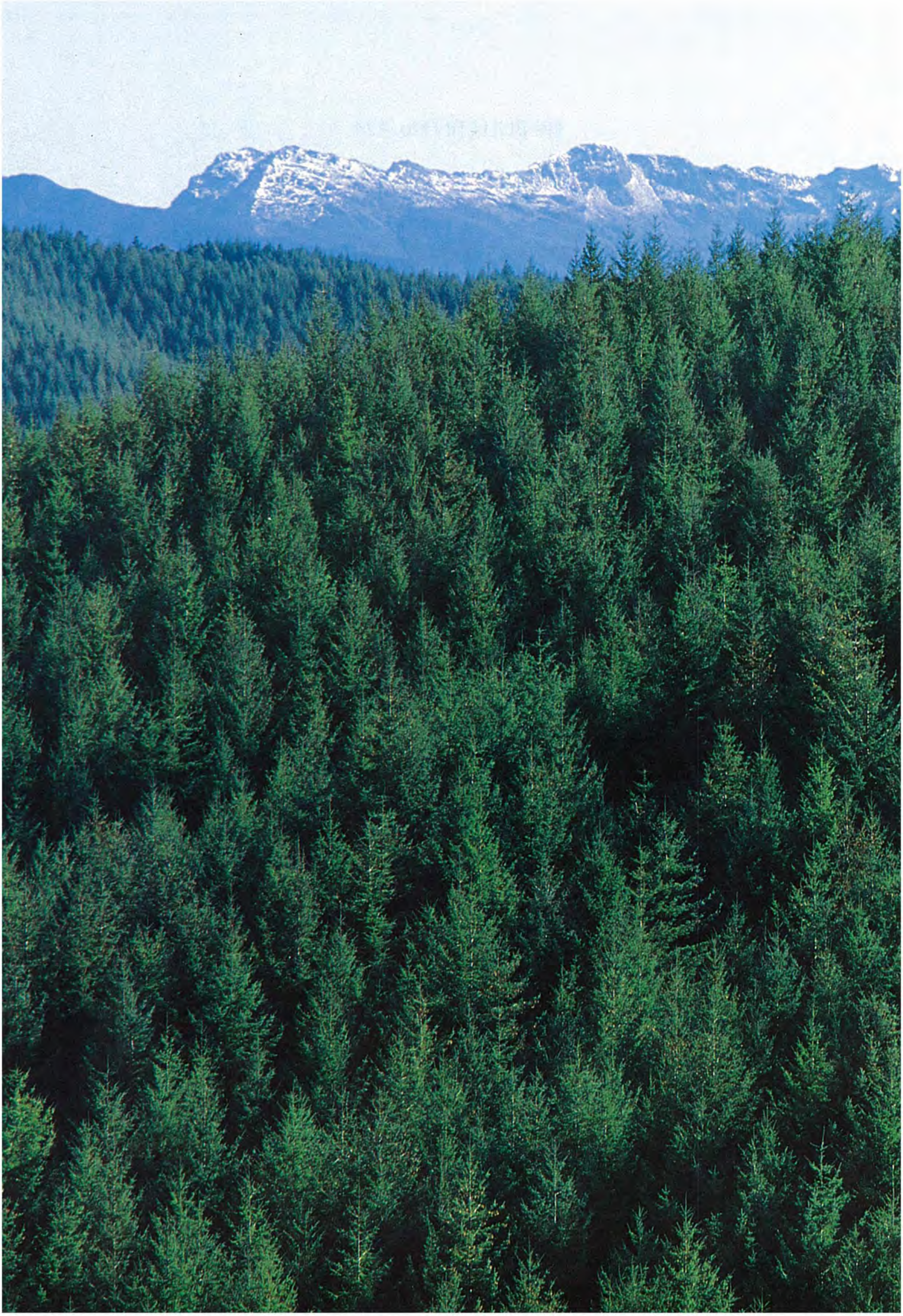
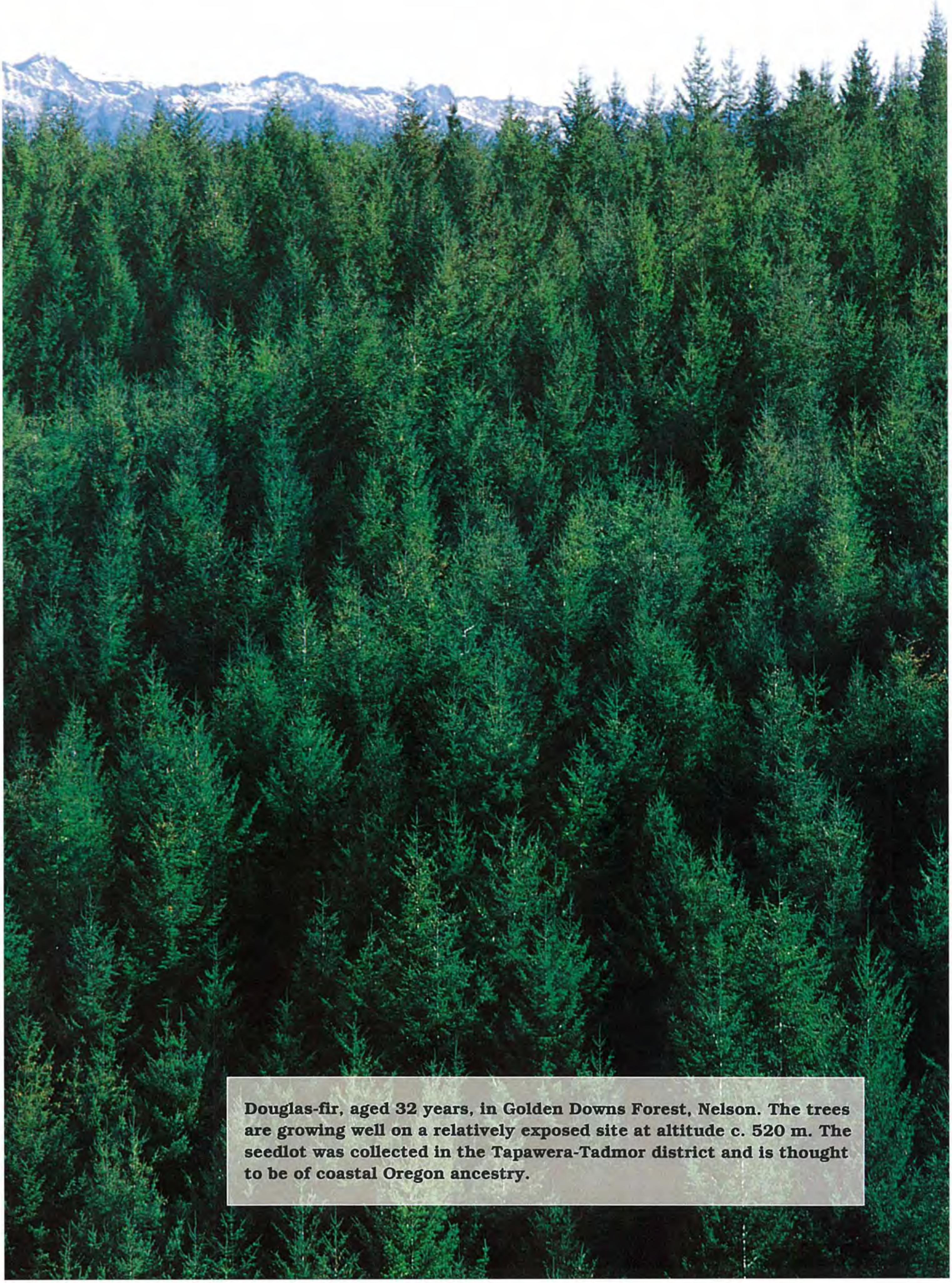




Douglas-fir, aged 32 years, in Golden Downs Forest, Nelson. The trees are growing well on a relatively exposed site at altitude c. 520 m. The seedlot was collected in the Tapawera-Tadmor district and is thought to be of coastal Oregon ancestry.

ISSN 0111-8129
ODC 174.7 *Pseudotsuga menziesii* (931):232

CONTENTS

Seed stand RO 26 at Rotoehu Forest, aged 34 years. This vigorous stand was thinned at age 15 years to 200 stems per hectare. The seed origin is Fort Bragg (low elevation, California).

ABSTRACT

This booklet, the fourteenth in the Bulletin 124 series provides a general account of Douglas-fir*, *Pseudotsuga menziesii*, in New Zealand. Topics covered include its natural distribution, its introduction and history in New Zealand, its role as an introduced species, recognition in the field, the significance of pests and diseases, and information on local seed sources.

KEYWORDS: *Pseudotsuga menziesii*, Douglas-fir, seed sources, recognition, silviculture, utilisation, role, provenance trials, New Zealand

INTRODUCTION AND HISTORY

Douglas-fir, *Pseudotsuga menziesii*, is native to western North America, where it is one of the most valuable and commercially important timber species. In New Zealand it ranks as the second most important softwood after radiata pine and in 1994 occupies over 60,000 ha, about 5% of the total plantation forest area.

Natural Distribution and Ecology

Pseudotsuga is a small genus of evergreen conifers occurring naturally in western North America, Japan, Taiwan and China. Included in the past in *Picea, Tsuga, Abies* and even *Pinus*, these species were eventually recognised as being sufficiently distinct in botanical characteristics to merit a genus of their own. Although in the past more than twenty species of *Pseudotsuga* have been described, as few as four are now recognised. These comprise two quite distinct North American species—*P. menziesii* (Douglas-fir) and *P. macrocarpa* (bigcone Douglas-fir)—and two very similar and closely related Asian species—*P. sinensis* (Chinese Douglas-fir) and *P. japonica* (Japanese Douglas-fir).

In North America *P. menziesii* covers immense areas of the Pacific Northwest, and is found on mountain ranges from British Columbia to Mexico. There are two varieties of *P. menziesii*—*P. menziesii* var. *menziesii*, the Douglas-fir of the timber industry, and *P. menziesii* var. *glauca*, Rocky Mountain Douglas-fir. These two varieties occur together in southern British Columbia and north-eastern Washington, but elsewhere their natural ranges are distinct.

The commercially prominent variety of Douglas-fir occurs in a broad coastal band which lies to the west of the coast range in British Columbia, the Cascade Range in Washington and Oregon, and the Sierra Nevada in northern California. Its range extends from Lat. 55°N in British Columbia to Lat. 35°N on the Californian coast. Rocky Mountain Douglas-fir occupies more inland sites in the mountain ranges and has a much more extensive range, from central British Columbia to central and southern Mexico. Its natural habitat includes the northern mountainous regions of south-western Alberta, eastern Washington and Oregon, Montana, Idaho, Wyoming and Colorado, plus, in the south, the mountains of Utah, eastern Nevada, Arizona and New Mexico, the extreme west of Texas, and central and southern Mexico. The natural ranges of the two varieties of *P. menziesii* are shown in Fig. 1.

The commercially important variety of Douglas-fir grows in regions which have generally mild climates that are humid except for a dry period in summer. Throughout its latitudinal range it occurs close to sea level, but it also rises into the mountains, reaching altitudes of about 800 metres in British Columbia and approximately 1800 metres in California, where there is a higher rainfall (920 to 3200 mm). Near the sea, precipitation is augmented by a

* Throughout this bulletin Douglas-fir has been hyphenated in line with North American usage

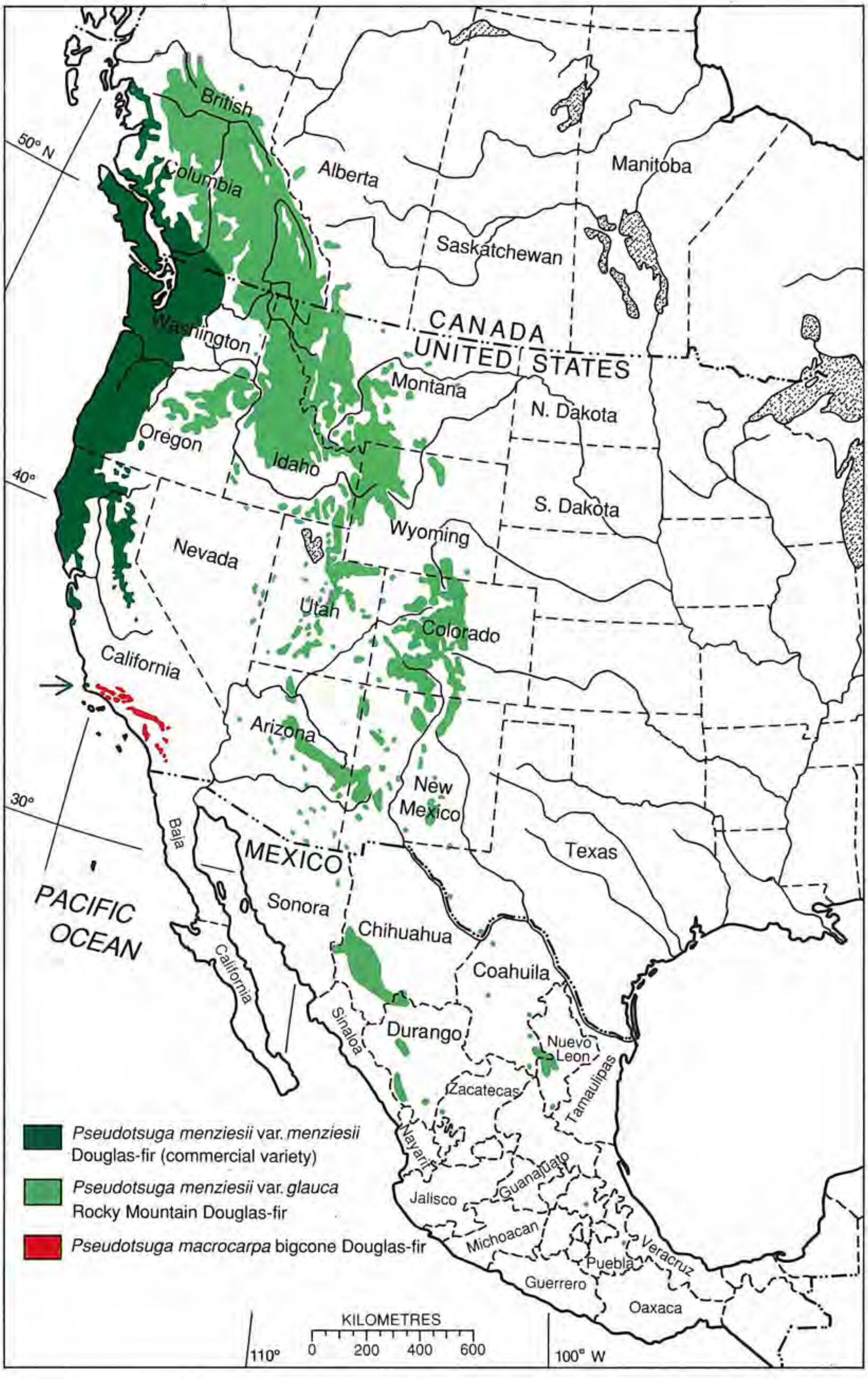


Fig. 1 - Natural distribution of *Pseudotsuga menziesii* and *Pseudotsuga macrocarpa* (based on Little, 1971).

copious fog-drip, caused by the effects of the cold, south-flowing "Japanese" ocean current on neighbouring warm air-masses. At high elevations inland and in the north much of the precipitation occurs as snow which may accumulate to depths of 3 m or more. In its natural habitat Douglas-fir thrives on well-drained soils of sedimentary or glacial origin, or of volcanic origin at higher elevations, which are usually mildly acidic (pH 5.0 to 5.5).

Throughout the drier, central part of its range, Douglas-fir forms vast, almost pure, even-aged stands. To the north it gives way to western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), and at higher altitudes to true firs (*Abies* species). Further south it tends to be gradually replaced by ponderosa pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*), incense cedar (*Calocedrus decurrens*) and various oaks (*Quercus* species). Within their respective natural ranges, coast redwood (*Sequoia sempervirens*) and red alder (*Alnus rubra*) are characteristic associates of Douglas-fir.

The other North American species, *Pseudotsuga macrocarpa* (bigcone Douglas-fir), has a relatively restricted range in the mountains of southern California extending from the Santa Inez Range to within 50 km of the Mexican border. The two Asian species each have a scattered distribution and are rather rare. *Pseudotsuga sinensis* (Chinese Douglas-fir) is found in a number of provinces in southeastern China, in Sichuan and Yunnan, and in Taiwan, and *P. japonica*, Japanese Douglas-fir, occurs in the mountains of south-eastern Japan.

History in New Zealand

The first recorded introduction of Douglas-fir into New Zealand was of a single plant, shipped in 1859 from Veitch's nursery near Exeter, England to J.B.A. Acland of Mt Peel Station, Canterbury. (Acland is credited with receipt, in the same year, of the first radiata pine seed to reach New Zealand).

Six years later, in 1865, Ludlam recorded Douglas-fir growing at the property of Thomas Mason at Hutt, Wellington. In 1868 some seed was imported to Dunedin from a San Francisco supplier, possibly the firm of Miller and Sievers, and seed was also sown at Albury homestead in south Canterbury in the following year. In 1871, T.H. Potts recorded Douglas-fir growing as a young tree at Lyttelton.

In 1874 and 1875 Sir James Hector, who in 1868 had been authorised to establish the Wellington Botanic Garden, imported about 11.5 kg of seed which had been collected by Professor Kellogg, a well-known Californian botanist. In 1879 a further 1.8 kg of seed was imported from Miller and Sievers of San Francisco.

From about 1870 on Douglas-fir was used for amenity and farm plantings in the South Island, especially in Canterbury where some fine old trees and plantations may still be seen in the foothills. It was tried in State Forests in the Rotorua district from about 1896, and planted there on a wider scale from 1901. Early plantings in State Forests in Tapanui district, west Otago, also date from the turn of the century.

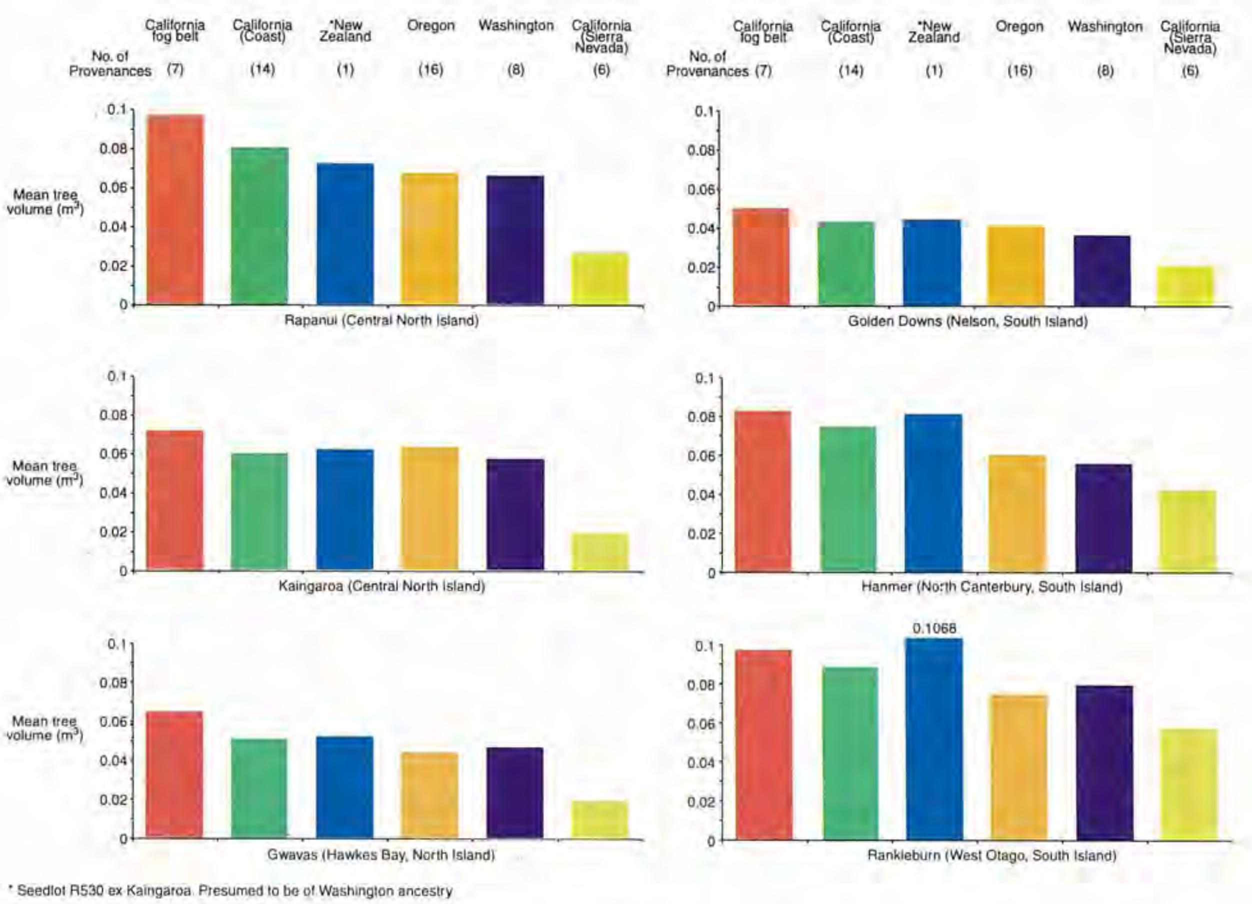
Before 1926 no accurate records were kept of the origins of seed reaching New Zealand. The main importer of seed in this early period was the Lands and Survey Department (the parent body of the later-formed State Forest Service). It is probable that most Douglas-fir seed obtained by the Department between 1902 and 1914 came from Washington and Oregon, with a lesser amount from British Columbia.

Between 1926 and 1974, a total of 3,000 kg of seed was imported by the New Zealand Forest Service from North America. Approximately 97% of this was from sources in Washington and Oregon and this seed has formed the basis of the New Zealand Douglas-fir industry. Of the remainder, 1% was from British Columbia and 2% from California. Californian seed was the last to be imported (74 kg between 1956 and 1972). Since 1926, the bulk of Douglas-fir seed (72%) has been collected within New Zealand, mostly from plantations originating from seed obtained from Washington and Oregon.

Provenance Trials and Seed Source Tests

A research programme investigating performance of Douglas-fir provenances in New Zealand was started in 1955 at the Forest Research Institute. The first trial series of 35 provenances was established in 1957; these consisted mostly of commercial seedlots from Washington and Oregon but included four New Zealand provenances. A second series, established in 1959, consisted of 45 provenances from Californian and Oregon coastal populations and one New Zealand provenance.

The 1957 trials were assessed at age 6 years. Low altitude, Washington seedlots were generally the tallest, but the four New Zealand provenances also did well and were among the best at most sites. The 1959 trials (evaluated comprehensively at age 13 years and less intensively at age 30 years) provided a fuller picture, showing the relative performance over a range of sites of the major Douglas-fir provenance groups of interest in New Zealand (Fig. 2).



* Seedlot R530 ex Kaingaroa. Presumed to be of Washington ancestry

Fig. 2 - Relative mean tree volumes for provenance groups of Douglas-fir at six New Zealand sites

Provenances from low elevation localities in the Californian coastal fog-belt performed outstandingly at all sites, and also generally maintained good form. Consequently, the fog-belt was noted as a prime source for future Douglas-fir selections. Collectively, coastal Californian provenances were generally more vigorous than those from Oregon and Washington. By contrast, provenances from the Californian Sierra Nevada were distinctly less vigorous than other groups. The single New Zealand provenance represented in the trials (from Kaingaroa, and presumed to be of Washington ancestry) fared well in aggregate performance, and grew especially well at the southernmost site (Rankleburn).

The rankings of the best eight provenances at age 13 years are shown in Table 1. Seven of these were from seedlots collected in the Californian coastal fogbelt (Fig. 3), and one was from seed collected in Kaingaroa Forest. The coastal fog belt has the most "maritime" climate within the Douglas-fir region, characterised by summer fogs, moderate temperatures with small daily and annual ranges, and infrequent frosts.

In addition to the provenance trials, tests were established in 1971 and 1974 to compare the quality of local seed sources in New Zealand. Results showed that seedlots from a number of South Island sources (e.g., Queenstown, Naseby, Wanaka) were slow growing and should not be used again. They are thought to have originated from British Columbia. Other seedlots from low elevations in Oregon were faster-growing, while progeny from a seed stand developed in Ashley forest, thought to be of coastal Oregon ancestry, proved in the tests to be well-adapted over a wide range of sites. Although not included in the tests, the few seed stands of low-elevation coastal Californian origin (photograph facing page 1) available in New Zealand are considered to be valuable, their parent seedlot having performed well in provenance trials.

Breeding Programme

A breeding programme for Douglas-fir was started in 1970, with the selection in Kaingaroa and Whakarewarewa Forests of 125 trees of probable Washington origin, followed by planting in 1972 of open-pollinated progeny trials. However, later assessment of the 1959 provenance trials at age 13 years showed the overall superiority in growth rate of provenances from the Californian and Oregon coastal fog-belt. This suggested that the earlier selections from the Kaingaroa, ex-Washington stands were unsuitable as the basis for a breeding programme.

The programme was reactivated in 1987. A different group of 200 trees was selected, on criteria of superior health and growth rate, good stem straightness and light regular branching. Mostly these were from seedlots originating in the fog-belt zones of coastal California and southern Oregon and included in the 1959 provenance trials. Some selections however, were from the best progenies in the 1972 progeny tests and other coastal Washington sources. In 1989, 185 of the selected trees were grafted into a prospective orchard at Waikuku, North Canterbury, by Proseed New Zealand Ltd.

One of the first projects approved by the FRI-Industry Douglas-fir Cooperative (formed in 1993) was to select more parent trees in the desired coastal fog-belt provenances in North America to augment that relatively small resource. Currently, seed has been obtained from over 240 selected parents, either collected by NZ FRI crews in mature stands in California and Oregon or supplied by United States Companies and the United States Forest Service from select clones in orchards or from select trees.

The result is a breeding population, available as grafts or as seedling progenies, of over 400 selected trees, separated into two main breeding units.

TABLE 1 - Rankings of the best eight provenances* at age 13 years in the 1959-series Douglas-fir provenance trials

Provenance	Origin	Overall ranking	Ht (m)	Diam. (cm)	Straightness (1-9)	Wood Density (kg/m^3)
659	Stinson Beach, California	1	10.4	13.6	5.2	406
641	Four Mile, Oregon	2	10.0	13.5	5.0	404
647	Mad River, California	3	10.6	13.5	5.2	390
642	Berteleda, California	4	10.6	14.0	5.3	385
660	Santa Cruz, California	5	10.7	14.0	4.7	378
654	Caspar, California	6	10.4	13.3	4.9	380
530	Kaingaroa, New Zealand	7	9.8	13.2	4.9	388
649	Dehaven, California	8	9.8	12.9	5.5	386

* With the exception of Lot 530 (from a plantation in Kaingaroa Forest, New Zealand), provenances originate from the coastal fog belt in California and Oregon (see Fig. 3 below).

Fig. 3 - Geographic origin of the seven highest ranked native provenances in the 1959 series of Douglas-fir provenance trials.

Fig. 4 - 1/0 Douglas-fir seedlings at Owhata Nursery, Rotorua. Left: Dense, vigorous and yellowish stock of Californian provenance (seed imported from Fort Bragg); right: shorter and darker green Washington provenance (seed ex Kaingaroa Forest, New Zealand).

The first improved commmercial seed will be produced from the New Zealand-selected clones in the Waikuku orchard. This seed will be mainly characterised by the superior volume growth of the Californian fog-belt provenances. Future cycles of improved seed or propagules will be generated by a breeding plan based on recurrent selection, mating and testing of clones, initially from the Waikuku orchard and later from the larger breeding population derived from the 400 selected parents.

A progressive breeding strategy has still to be evolved. Initially it is expected to rely on widespread progeny testing to identify a versatile breeding population for use over the range of New Zealand sites. The most suitable provenances or strains for the upper limits of future planting still have to be identified, although so far plantations of Washington or Oregon seed origin have performed well there.

Pests, Diseases and Hazards

After more than a century of cultivation in New Zealand Douglas-fir remains a relatively healthy species. Nevertheless it plays host to a wide variety of insect pests and pathogenic fungi, and is affected by both environmental factors and animal damage. The most serious threat to its health to date has been from Swiss needle-cast fungus, which has caused a significant reduction in the growth of many older stands.

Fungi

Phaeocryptopus gaeumannii, Swiss needle-cast fungus, parasitises the needles of Douglas-fir and may cause chlorosis and premature defoliation of older needles (Fig. 5). It occurs

Fig. 5 - Damage caused by *Phaeocryptopus gaeumannii* in Douglas-fir provenance trials aged 11 years, Gwavas Forest, Hawkes Bay. The heavily infected provenance in the foreground is from Inskip, California (high elevation, inland site). The less heavily infected provenance behind is from Florence, Oregon (low elevation, coastal site).

throughout the natural range of Douglas-fir in western North America, usually causing few harmful effects. Where Douglas-fir has been planted as an exotic, however, as in the eastern half of the United States, or in Europe or New Zealand, a significant reduction in growth has been associated with attack by *P. gaeumannii.*

The fungus was first found in New Zealand at Taupo in 1959. It has since spread to almost all areas where Douglas-fir has been planted. Its effect has been greatest in older, unthinned stands. The life-cycle of the fungus has been well recorded in recent research (Hood, 1983), and data for all Douglas-fir permanent sample plots were analysed to assess the extent to which growth declined in association with the appearance of *Phaeocryptopus*. Comparisons made before and after the onset of *Phaeocryptopus* attack indicated that basal area increment of Douglas-fir had been lowered by at least 25% (in an extreme case, by 40%). However, these results reflect a complex of influences, including insect defoliators, and are not solely attributable to the needle-cast fungus.

There is also some evidence of differences among Douglas-fir provenances in their capacity to retain older needles after infection. For example, in studies at Hanmer Forest, Canterbury, a greater loss of older needles was recorded in an interior Californian provenance than in one from Kaingaroa, presumed to be of Washington ancestry. Observations made in the 1970s in provenance trials which were planted in 1957 and 1959 in Kaingaroa Forest showed that needle loss and chlorosis due to the fungus were more apparent among obviously unthrifty trees, or "off-site" provenances than among those which were well adapted to the site.

While the defoliation of Douglas-fir in New Zealand, caused by a complex including *Phaeocryptopus*, has caused some loss in productivity, overseas experience suggests that implications for the future may not be serious. Good management, including the use of appropriate genetic material, careful siting and lower-stocking silvicultural regimes should partly offset the productivity loss due to Douglas-fir defoliators.

Other common forest fungi have been recorded attacking Douglas-fir, but most are of little economic importance. Root-rot fungi (*Armillaria* spp.) attack Douglas-fir but mortality rates are much lower than for *Pinus radiata*. *Diplodia* leader dieback has been recorded both on young trees and as a nursery disease among seedlings. In either case, the onset of infection, which is likely to be localised, is usually attributed to stress, drought or, in the nursery, to chemical or wrenching damage. Seedlings and young plants of Douglas-fir are host to other nursery fungi including *Dothistroma pini*, *Botrytis cinerea*, *Telephora terrestris* (the smother fungus) and the usual fungal agents of "damping off", but these are readily controlled by chemical sprays.

Insects

A number of insects feed on Douglas-fir foliage including minor pests such as the native bronze beetle, *Eucolaspis brunnea*, the grass grub, *Costelytra zealandica* and several other chafer beetles. More visible damage is caused by the caterpillars of several native species of moth. The tortricids *Ctenopseustis obliquana*, *Planotortrix* spp. and *Epiphyas* sp. cause apical damage to young Douglas-fir by feeding on leaves, buds and soft stems while sheltering under a webbing of silk. Looper caterpillars of the geometrid moths *Declana floccosa*, *Pseudocoremia fenerata* and, more significantly, *Pseudocoremia suavis* feed on the foliage of their hosts which include Douglas-fir. Populations of *P. suavis* usually remain at endemic levels but occasionally, epidemics have been recorded in exotic conifer forests, notably attacks on Douglas-fir in Kaingaroa Forest in 1970, 1972 and 1978.

One of the more important insect pests is the Douglas-fir seed chalcid, *Megastigmus spermotrophus*, the larvae of which eat the contents of Douglas-fir seed. A higher proportion of seed is affected, and losses are probably greatest, in poor seed years which often follow good seed years favourable to chalcid build-up. Periodic losses of up to 20% of the seed crop are suspected, but generally the effect on Douglas-fir seed production is not great (Nuttall, 1989). During the period 1955-57 unsuccessful attempts were made to introduce a parasite, *Amblymerus apicalis* to control the chalcid.

Fig. 6 - Frost damage to Douglas-fir in Kaingaroa Forest. The damage was caused by a 4°C frost in November in an area where air ponding had occurred.

The wood of Douglas-fir is relatively resistant to insect pathogens. The native longhorn beetle *Navomorpha lineata* occasionally bores into branches and from there into the main stem, while larvae of the beetle *Pachycotes peregrinus* may bore in logs which have not been promptly extracted or sawn. Export of infected logs is prohibited.

Frost

Damage and mortality caused by late spring or summer frosts are important factors causing failure of Douglas-fir plantings (Fig. 6). In areas where air-drainage is poor and ponding occurs or where severe frosts occur at the time when seedlings are flushing, soft foliage may be killed and buds and bark may be damaged. Frost damage can be followed by fungal attack from *Diplodia* or *Phomopsis* and mortality can be high.

Wind and exposure

It is not uncommon for Douglas-fir in New Zealand to suffer leader-loss and general malformation of the crown as a result of damage by strong winds. However, recovery is generally rapid and effective with leader replacement by a lateral branch occurring within two years, leaving little stem deformity.

Other hazards

Rabbits, hares, goats, sheep, cattle and deer have all caused substantial browsing damage to newly-planted Douglas-fir. Possums have limited the use of Douglas-fir in Westland, largely due to the habitat and unrestricted access to plantations provided by adjoining cutover native forest, but they have not been as troublesome elsewhere.

RECOGNITION

General description of *Pseudotsuga*

Habit: Large evergreen spruce-like trees with branches in indistinct whorls or clusters.

Foliage: Leaves single, spirally arranged, with a more or less twisted base, roughly two-ranked, green and grooved above with two whitish or glaucous bands beneath. Leaf tip blunt and rounded or more or less pointed (American species) or notched (Asian species).

Branchlets: Shallowly grooved, minutely hairy or without hairs, leaf scars small and more or less circular, slightly raised.

Winter buds: Slender, spindle shaped, sharp pointed with shiny brown overlapping scales.

Cones: Solitary at the ends of short branches, pendulous when mature, maturing in one year, falling some time after seed dispersal. Young cones generally green (American species) or purplish (Asian species). Cone scales rounded, overlapping, persistent. Three-pointed bract scales exerted between cone scales usually a conspicuous feature of the cone (Fig. 11). Male cones catkin-like, solitary, 1–2 cm long.

Seed: Two to each cone scale, each with a large wing partly enveloping the seed.

Pseudotsuga menziesii (Mirbel) Franco—**Douglas-fir**

Habit: A tall to very tall tree reaching to over 50 metres in height and 200 cm dbh in New Zealand and to at least 100 metres height and 400–500 cm dbh in its natural habitat in North America. When young the crown is conical but becomes more columnar with age, remaining slender and lightly branched till old when the crown eventually becomes broad and flat. The trunk is single, straight and columnar with more or less horizontal branches. The lower branches often curve downwards, especially in old trees. Foliage is dense on the branchlets which often form heavy pendulous masses in older trees.

Bark: In young trees smooth, dark greyish green to purplish brown, resin blistered, becoming thick, rough and scaly, grey or grey-brown with deep brown to reddish brown longitudinal fissures (Fig. 8). In some old trees quite corky.

Foliage: (Fig. 9). Leaves 1.5–3.0 cm long (occasionally to 4 cm) long, 1–1.5 mm wide (occasionally wider), yellowish green to dark bluish green above, with two pale bands below, blunt or bluntly pointed at tip (not notched). Leaves pointing forwards, more or less parted on top of the shoot, parting more distinct on shaded shoots. Foliage has a fruity smell when crushed. Leaves persist on the tree for 8 or more years.

Branchlets: Slender and flexible, yellowish green at first, becoming brown, and later grey-brown, ridged and grooved, with erect pale hairs in the first year, becoming glabrous (without hairs), leaf scars small, circular and slightly raised.

Winter buds: Spindle shaped—long, narrow and sharply pointed with overlapping scales (Fig. 10), glossy brown, without resin or slightly resinous near the base of the scales.

Cones: Near the ends of shoots, numerous, pendulous, with a curved stalk 0.5–1 cm long, cylindric -ovoid, 4–10 cm long and 2–5 cm wide (open), green or in some trees reddish when immature, ripening to dull brown and falling after shedding seed. Cone scales thin, rounded, relatively soft, with a smooth, minutely pubescent, obscurely striated surface. Three-pointed tongue-like bracts protrude conspicuously between cone scales covering their centres, pointing towards the cone tip (Fig. 11). Each bract has a long slender, sharp pointed central awn (1–1.5 cm long) and two shorter sharp-pointed lateral lobes. Male cones pendulous, 1.2–2.0 cm long, and yellow when ripe (Fig. 12).

Seed: Shining brown above, much paler and mottled below, 6–8 x 4–5 mm with an ovate-oblong wing, pale yellowish brown with darker striations (Fig. 13).

Pseudotsuga menziesii* var. *glauca (Beissner) Franco, **(includes *P. flahaultii*** Flous **and *P. macrolepis*** Flous)

The Rocky Mountain variety, *P. menziesii* var. *glauca*, generally differs from the coastal variety, *P. menziesii* var. *menziesii*, in the following features:

- Generally a smaller, more compact tree with markedly glaucous (blue-green) foliage (Fig. 14).
- Bark thinner, scaly, greyish or blackish.
- Leaves usually shorter and wider, 1.5–2.5 cm x 1.4–1.7 mm and tend to be thick and rounded at the tips.
- The branchlets are variable in pubescence, and often hairless.
- Buds are resinous (they may be more or less covered in whitish resin).
- Bud scales often fringed.
- Very young cones often reddish.
- Cones generally smaller with bracts often reflexed (Fig. 14), not pointing towards tip of cone as in var. *menziesii*.

Various intermediate intergrading forms between the two varieties occur and the above distinguishing features are not always present in combination.

Distinguishing characteristics of *Pseudotsuga menziesii*

Pseudotsuga menziesii is easily recognised by the combination of narrow, pointed, spindle-shaped, glossy winter buds, the soft leaves arranged in two loose ranks and the very distinctive light-brown pendulous cones with conspicuous three-pointed bracts protruding between and beyond the cone scales. The leaves have a fruity smell when crushed.

Pseudotsuga menziesii can be distinguished from other *Pseudotsuga* species by its distinctive habit (conical to columnar with light branches), its bark (resin blistered when young and becoming very thick with age) and the cones, which have bracts much longer than the cone scales.

Other species

Pseudotsuga macrocarpa (Vasey) Mayr, the other North American species, has much longer cones (10–18 cm long) and hard, sharp-pointed leaves (leaves are soft and blunt in *P. menziesii*).

The Asian species, *Pseudotsuga sinensis* Dode* (Fig. 15) and *Pseudotsuga japonica* (Shirasawa) Beissn., are distinguished by their notched leaf tips, usually purplish young cones and more or less recurved bracts on the cones.

The more prominent characteristics of the species of *Pseudotsuga* are summarised in Table 2. Whereas the two North American species, *P. menziesii* and *P. macropcarpa*, are quite distinct, differences between the Asian species are slight and apparently not always consistent.

TABLE 2 - Summary of the more prominent characteristics of *Pseudotsuga* species

<table>
<tr><th>P. menziesii
(including var. glauca)</th><th>P. macrocarpa</th><th>P. sinensis</th><th>P. japonica</th></tr>
<tr><td>Leaves 1.0–1.5 mm wide</td><td colspan="3">Leaves 1.5–2.0 mm wide</td></tr>
<tr><td>Leaves parted above shoot but not pectinate (comb-like) in arrangement</td><td colspan="3">Leaves mostly pectinate (comb-like) in arrangement</td></tr>
<tr><td>Cone scales thin</td><td colspan="3">Cone scales relatively thick</td></tr>
<tr><td>Bracts much longer than cone scales, not usually reflexed in var. menziesii</td><td colspan="3">Bracts as long as or only slightly longer than cone scales—often reflexed</td></tr>
<tr><td colspan="2">Leaf tips not notched</td><td colspan="2">Leaf tips notched</td></tr>
<tr><td>Leaves dark green, or blue-green, soft, blunt tipped</td><td>Leaves light green, hard, sharp pointed</td><td>Leaves dark green</td><td>Leaves light green</td></tr>
<tr><td colspan="2">Young cones usually greenish</td><td colspan="2">Young cones usually purple</td></tr>
<tr><td>Cone length 4–10 cm</td><td>Cone length 10–18 cm</td><td>Cone length 3.5–8.0 cm</td><td>Cone length 3.0–5.5 cm</td></tr>
<tr><td>Young shoots yellowish green, pubescent</td><td>Young shoots pale or reddish brown, pubescent at first</td><td>Young shoots red-brown, usually pubescent</td><td>Young shoots light yellow-grey, without hairs</td></tr>
</table>

* *Pseudotsuga sinensis* includes *P. wilsoniana* Hayata and *P. forrestii* Craib

Fig. 7 - Open-grown tree of good form, Tapawera-Tadmor area, Nelson

Fig. 9 - Foliage and cones of *P. menziesii*

Fig. 10 - Winter buds of *P. menziesii*

Fig. 8 - Typical bark of mature tree

Fig. 11- Cones of *P. menziesii*

Fig. 13 - Seed of *P. menziesii*

Fig. 12 - Male cones of *P. menziesii*

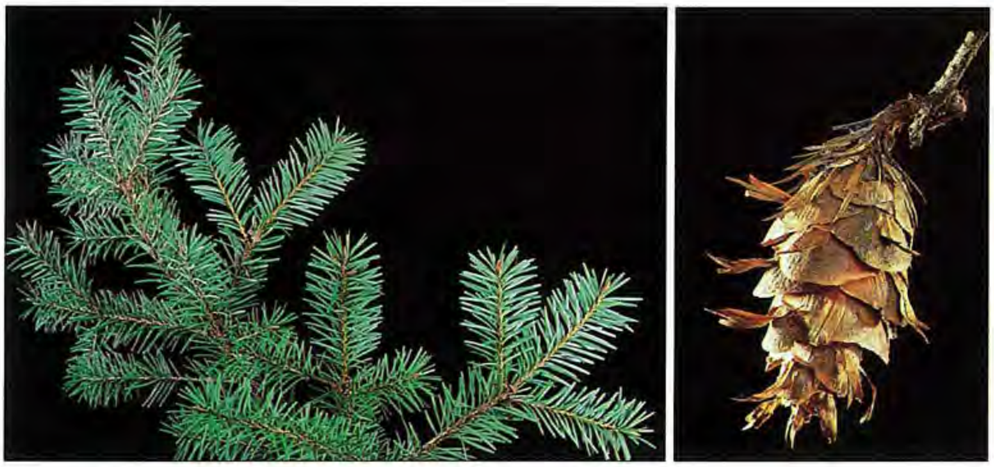


Fig. 14 - Foliage and cone of *P. menziesii* var. *glauca*. Note reflexed bracts on cone and glaucous foliage.

Fig. 15 - Foliage and cone of *P. sinensis*.

ROLE OF THE SPECIES

Present Extent

In 1991 approximately 63,500 ha were planted in Douglas-fir with just over half (approx. 33,000 ha) in the North Island and the remainder in the South Island (Table 3).

TABLE 3 - Extent of Douglas-fir in New Zealand (1990-1991)

Region	April 1990 (ha)	April 1991 (ha)
NORTH ISLAND		
Northern	5	2
Central	36,309	31,571
Southern	1614	1587
SOUTH ISLAND		
Nelson/Marlborough	11,583	11,439
West Coast	556	556
Canterbury	5292	4663
Otago/Southland	10,936	9473
Holdings < 100 ha (both islands)	9771	4187
TOTAL	76,066	63,478

Source: National Exotic Forest Description (Ministry of Forestry)

The approximate extent of Douglas-fir planting since 1991, estimated on the basis of number of seedlings sold in nurseries, is:

1992- 1100 ha planted (presumed to be re-stocking of felled areas)
1993- 1000 ha (re-stocked), 300 ha (new planting)

Since 1974 (at which time the total area of Douglas-fir in State forests was about 42,000 ha) the planted area has increased substantially, particularly in the central and southern North

Island regions and in Nelson/Marlborough, Canterbury and Otago/Southland. However, between 1990 and 1991 there was a drop in the planted area of 12,600 ha due to increased harvesting of older age classes for the booming export log market. Overall, Douglas-fir has been planted at a relatively steady rate averaging 1500 ha per year, and new planting is expected to continue at least at this rate.

An age-class breakdown (1991) for major holdings of Douglas-fir in New Zealand shows that 75% of the plantings are less than 30 years old (Table 4).

TABLE 4 - Age-class distribution of New Zealand Douglas-fir

Amount	Age Class (years)						
	1–10	11–20	21–30	31–40	41–50	51–60	61–80
Area (ha)	15,661	13,047	16,909	5673	859	2944	4198
% of total	26	22	29	10	1	5	7

Siting

Douglas-fir grows well over most of the country in areas which receive moderately high rainfall (1000 to 1500 mm annually). However, it has not thrived in the north of the North Island. This has been attributed to a combination of warmer conditions, unsuitable provenances, heavy clay soils and exposure to salt-laden winds.

Growth is generally best on moist, free-drained, uncompacted soils. Chlorosis and growth stagnation can result from poor drainage and waterlogging associated with pan formations and podzols. Douglas-fir has shown some susceptibility to drought, e.g., when planted as a shelterbelt species on the Canterbury Plains (Fig. 16). On sites where rainfall is less than 1000 mm Douglas-fir can grow well on shadier, usually southerly aspects.

Altitudinal limits for good growth in Douglas-fir were given by Spurr (1961) as 900 m a.s.l. in the North Island and 750 m in the South Island. More recent information shows these estimates to be conservative. Douglas-fir is growing at commercially productive rates well above 800 m in the Craigieburn Range in Canterbury, (N. Ledgard, pers. comm.) and up to 920 m at Karioi in the central North Island. Generally, it is more windfirm than radiata pine, but at all altitudes exposure is considered to be the main limitation to its satisfactory growth in New Zealand. Orientated at right angles to a prevailing west to south-west airflow, New Zealand experiences colder and stronger winds than those of the low-altitude coastal regions of the natural habitat. Nevertheless, Douglas-fir can recover remarkably well from exposure damage, and during the first 20 years of growth it can often replace stripped or deformed leaders with little permanent stem malformation. Exposure damage can be reduced by planting at stocking levels sufficiently high to create mutual shelter among the establishing trees. Frost damage is very likely to occur wherever air-drainage is poor, and frost hollows should be avoided. Snow is tolerated better by Douglas-fir than by radiata pine, the crown form and branching arrangement of Douglas-fir allowing shedding of snow before bending or breakage occurs.

On some favourable higher altitude sites Douglas-fir exhibits a significant growth advantage over other species. With the added advantages of its tolerance of wind, snow and low winter temperatures Douglas-fir is often the best species for moister areas of high country.

Fig. 16 - Douglas-fir killed by drought in a shelterbelt on the Canterbury Plains. Adjacent radiata pine is unaffected.

On certain sites, especially on fertile ex-farmland sites in the South Island, Douglas-fir has shown malformation in apical leader and branch growth around 12–15 years. This has been linked circumstantially to boron deficiency (N. Ledgard, pers. comm.).

Provenance in relation to site

Douglas-fir is now recognised as a major species and as the most appropriate choice for many mid- and high-elevation sites where increased effects of exposure must be tolerated. In the past Washington and Oregon provenances have grown well and have produced good timber trees in these situations, given the high initial stockings, delayed thinning and long rotations under which they have been grown (Fig. 17).

At lower elevations Californian provenances have now been shown to have faster growth rates and to produce higher volumes, and they appear to be the best choice for such situations. Trials comparing the performance of Californian and other provenances on severe sites will be necessary, but in the meantime it would seem prudent to continue to plant a proportion of stock of locally adapted Washington or Oregon provenances on the more exposed sites.

Establishment

Establishment practices for Douglas-fir are attracting renewed interest, not only because of a move to planting this species on higher elevation sites but also because of increasing problems with weeds, particularly on sites carrying a second-rotation crop.

Critical interacting factors which will influence success in establishing Douglas-fir are seedling quality, planting procedures, and weed control.

Seedling quality

Success with Douglas-fir is most assured when dormant, well-grown, correctly conditioned seedlings with moist roots are planted on sites free from weed competition. Douglas-fir generally grows more slowly than radiata pine over the first few years and sturdy stock of moderate to large size has the best survival and growth potential on most sites.

Larger sturdy stock is more resistant to browsing damage by hares and rabbits, competes better with weeds and inoculates new sites with beneficial mycorrhizae more effectively. Ideally, Douglas-fir seedlings should conform to the following general specifications:

• Height	30–60 cm
• Root-collar diameter	8–11 mm
• Shoot/root length ratio	No more than 4:1
• Root system	Fibrous, mycorrhizally active, moist at planting
• General condition	Dormant; cool-stored

However, the need for economy of production and planting efficiency may dictate modification to these general seedling specifications. Present container systems are not designed to accommodate large stock over 40 cm in height.

Contemporary nursery systems producing different types of stock are described in the Seed Users' Guide (B) page 32.

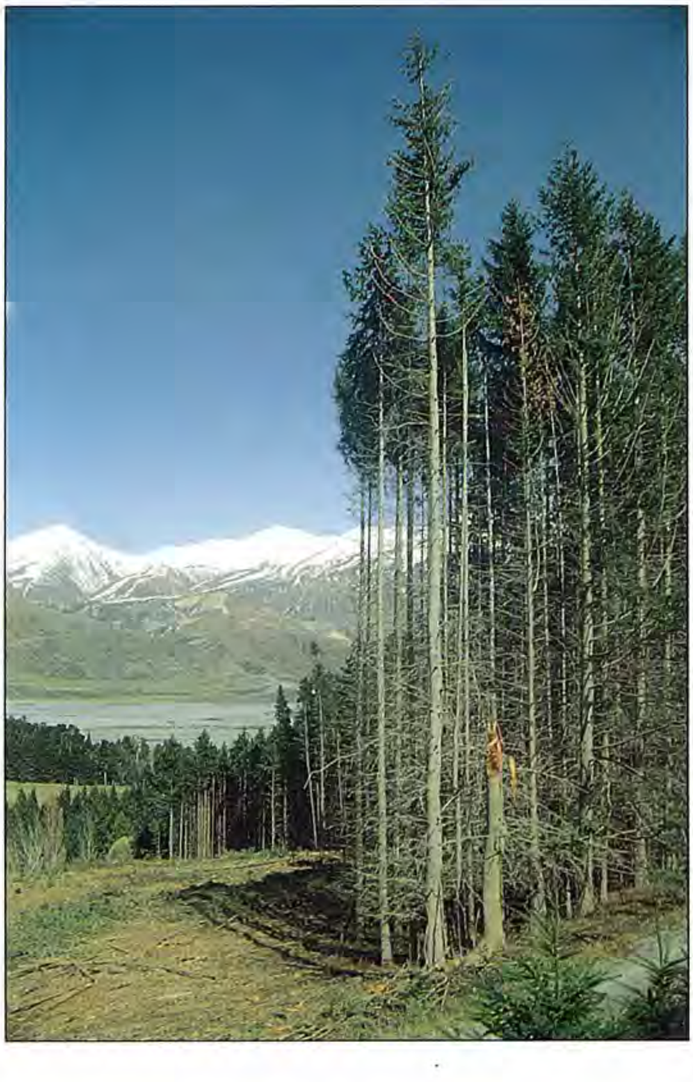


Fig. 17 - Douglas-fir plantation at Lake Coleridge, Canterbury, aged 63 years.

Planting Procedures

Despite their sturdy appearance, Douglas-fir seedlings are surprisingly delicate compared with radiata pine and any drying out of their fine root systems should be avoided. This is particularly important if, as often happens, Douglas-fir is the last species to be planted in the season, when soil and air temperatures are rising.

Achievement of high survivals should be a prime aim. Douglas-fir tends to extend its branches radially into crown gaps, where branch size increases considerably, so avoidance of stand gaps is important.

Weed Control

Douglas-fir is very sensitive to weed competition, considerably more so than radiata pine, and during the first two to three years following planting the area in the immediate vicinity of the tree should be kept as weed-free as possible. Douglas-fir seedlings are particularly sensitive to water depletion during spring and summer droughts and to excessive shading and physical suppression caused by weeds. Consequently growth may be severely retarded if weeds are not effectively controlled.

Douglas-fir is less tolerant than radiata pine of many forestry herbicides and so more caution is needed in their use and a high level of pre-plant site preparation is especially important. Before an area is planted, scrubweeds, grasses and herbaceous weeds should be killed with glyphosate (e.g., Roundup or Trounce) and/or metsulfuron (Escort). Escort however, should be used with considerable caution because of residues and Douglas-fir should not be planted on the sprayed site for at least two months (and possibly as long as nine months). Grazon (triclopyr) and Tordon Brushkiller (triclopyr + picloram) are also effective in controlling scrubweeds before planting. Gardoprim (terbuthylazine) is the only herbicide with a specific label recommendation for use with Douglas-fir, and can be sprayed directly over the top of the tree before bud burst (i.e., while the trees are dormant). Gardoprim controls grasses and most pasture weeds and may be mixed with Versatill (clopyralid) to extend control of broadleaved species. Gallant (haloxyfop) and Targa (quizalofop-p-ethyl) can also be applied over the top of planted Douglas-fir. However, there may be damage, particularly to new foliage, if additives (spraying oils or surfactants) are included.

Mycorrhizae

Mycorrhizal fungi have a beneficial association with the roots of Douglas-fir and may be essential for healthy growth of the tree (Fig. 18). Seedlings raised in low-lying, poorly drained nurseries have been found to be deficient in roots containing mycorrhizae, resulting in chlorotic stock which has lingered without growth for some years after planting.

Studies carried out at the Forest Research Institute since 1977 have identified at least 13 species of fungus having mycorrhizal association with Douglas-fir in nurseries or in plantations. One of the most important, *Rhizopogon parksii*, has been found associated with seedlings and with trees of all ages in the North Island, and with plantation trees in the South Island (although it has been encountered infrequently in South Island nurseries). On the other hand the mycorrhizal fungus *Suillus lakei* has been found commonly both in nurseries and among young trees in the South Island.

Fig. 18a - Douglas-fir seedlings before inoculation with *Rhizopogon parksii* (left) and after inoculation (right).

Fig 18b - Close up of mycorrhizae of *Rhizopogon parksii* on the roots of the seedlings.

Chlorotic symptoms shown by Douglas-fir seedlings in nurseries in both islands (at Cambridge Nursery, Waikato, in 1978 and at Edendale Nursery, Southland in 1982) disappeared after application of a spore suspension of *Rhizopogon parksii* supplied by the Forest Research Institute. Another method used to provide mycorrhizae has been to inoculate new nurseries by bringing in soil from under older Douglas-fir stands. Inoculation of a forest nursery with *Suillus* has not been tried.

Silviculture and Management

Douglas-fir has traditionally been grown to provide specific markets with timber for framing or engineering purposes. These are uses in which the critically important characteristics are stiffness and strength, factors which are strongly related to silviculturally controllable features such as branch size. More recently there has been a strong demand for export logs, including pruned logs of Douglas-fir. Many stands have been selectively pruned in the past, but little is known about the effects of pruning on growth and log quality. Many of the branches on Douglas-fir are small but there are a large number of them, and pruning costs are twice as much per tree as for radiata pine.

Fig. 19 - A late thinned stand of Douglas-fir aged 68 years, West Tapanui, Blue Mountain Forest, Otago.

Prior to 1970, stocking levels were relatively high (1.8 x 1.8 m spacing; 2990 stems/ha). High standards of planting, releasing and blanking proved extremely effective in producing good timber grades. Rotations were long (60–80 years), and thinning was often delayed to between ages 30 and 40 (Fig. 19). Douglas-fir showed a remarkable capacity to tolerate high stocking levels and to respond to delayed thinning. The high timber quality realised in these stands is partly attributable to the natural tendency of Douglas-fir branches to occur mainly in indistinct clusters at the end of the annual growth stages, a factor contributing to structural strength. Also, shaded branches tend to be suppressed quickly leaving sound knots within the stem.

Because of the radically changed economic climate, past silvicultural practices which have provided the structural timber now on stream would today result in prohibitive growing costs. Current silvicultural regimes aim to provide the desired quality of timber at a reasonable cost. These regimes require a much shorter rotation length of about 45 years, and lower initial stocking rates of approximately 1500 to 1600 stems/ha. Early thinning is essential to maintain diameter growth and promote a healthy green crown (Fig. 20) and should result in a final stocking of between 250 and 500 stems/ha.

In the past, many stands received a single production thinning when they were aged around 30 years (i.e., in the 1960s or 1970s), yielding 90–150 m^3/ha as small sawlogs. Current practice involves a waste thinning before age 20 to a stocking of 300–600 stems/ha if no further thinning is intended, or to 500–800 stems/ha if there is to be a later production thinning. This production thinning is usually scheduled at 25–30 years of age, with the stand being reduced to 250–300 stems/ha.

Current practices reported by forest owners lie within the following limits:

Mean Top Height (m)	Thinning	Stocking (stems/ha)
9	First (waste)	Initially c. 1600 (1200–2000)
or 14–16	First (waste)	300*–500 (exceptionally 800)
20–35	Production	250–500

* Stands thinned to waste to 300 stems/ha are mostly on steep terrain, and are unlikely to be production thinned.

Higher initial stocking rates are usually advisable on higher-altitude exposed sites where trees benefit from mutual shelter. Exceptions may be some high country sites, such as parts of the Mackenzie basin, which receive low rainfall (600–900 mm annually) and are not prone

Fig. 20 - Douglas-fir thinning and pruning trials aged 12 years, Kaingaroa Forest (visit by Douglas-fir Research Cooperative, 1994). The residual stocking is 250 trees per hectare.

to exposure. Branches on such sites are usually finer than is typical for Douglas-fir, and, provided establishment is full and even, stocking rates as low as 800–1000 stems may be acceptable (M. Belton, pers. comm.).

Research has shown that, in Douglas-fir, wood density is largely unaffected by increased diameter growth of the trees following thinning. Branch size is by far the most important factor affecting wood quality, especially strength and stiffness. An initial stocking level of 1600 stems/ha has been recommended to restrict branch index (the mean of the 16 largest branches per 4.8 m log) in the second log to less than 40 mm.

Douglas-fir in mixture

A survey completed in 1976 found that about 9% (5800 ha) of New Zealand Douglas-fir plantations were in the form of mixtures with other species. Most of the stands (71%; 4100 ha) were in the North Island. The most commonly planted secondary species were Corsican pine (*Pinus nigra*), European larch (*Larix decidua*), Japanese larch (*L. kaempferi*), contorta pine (*P. contorta*) and ponderosa pine (*P. ponderosa*).

The most common reason for planting mixtures has been to make up a shortfall of planting stock or seed in years of limited supply.

The use of mixtures is an option for the smaller woodlot grower, but it is difficult to create a plantation in which a self-thinning sequence occurs, and deliberate thinning is usually required to remove the secondary species.

Regeneration

Douglas-fir will regenerate freely around mature trees in the absence of browsing. This is especially obvious along undisturbed firebreaks or in clearings within stands. Where Douglas-fir adjoins stands of other species its shade-tolerant seedlings may spread as a thriving understorey well away from the original source.

Douglas-fir, which is less palatable to sheep than larch, contorta pine and radiata pine, can spread as wildings on to open country or pasture (Fig. 21). Significant viable seed production occurs at about age 12 years and failure to manage or remove young regenerating trees may result in "forestry by default", which may not be acceptable to the landowner.

Growth and Yield

Douglas-fir is highly regarded as a commercial timber species throughout the world, in part due to its fast growth relative to many other species. In the past the chief source of timber has been the natural forests of the American Pacific Northwest, usually referred to as "old growth". Today this resource is decreasing, and is being set aside for conservation and environmental preservation purposes. Its place is being taken by younger planted material, the so-called "second growth" Douglas-fir, with which New Zealand Douglas-fir is more comparable.

Douglas-fir can produce large volumes of timber in New Zealand, although generally only on rotations which are longer than for radiata pine. Profitability models (e.g., Fenton 1976) for Douglas-fir and radiata pine on high-quality sites (which represent the optimum growing conditions for each species) have been shown to favour radiata pine, largely because of the longer rotation needed by Douglas-fir and the smaller logs produced. On some sites however, usually at higher altitudes which are sub-optimal for radiata pine because of risks of wind

Fig. 21 - Spread of Douglas-fir wildings at Queenstown.

and snow damage, Douglas-fir can be a better performer. The respective growth rates and yields of the two species in part reflect the duration of their growing seasons. Douglas-fir has a distinct growing season from September to April in New Zealand. Growth stops completely for the winter, making the species more resistant to damage by snow or seasonable frost. (It remains susceptible, however, to out-of-season frosts). Radiata pine, on the other hand, can continue to grow throughout the year, as long as temperatures and moisture are adequate.

Volume growth in Douglas-fir is relatively slow for the first part of the rotation, i.e., until about age 30 years. After this, recoverable volume continues to increase as can be seen in Table 5. Douglas-fir generally reaches heights of 30-35 metres by age 40. Although it is unlikely ever to exceed heights of about 55 metres in commercial rotations, diameter growth is strongly maintained, and some of the oldest trees in New Zealand are still increasing in volume at 90 years of age.

TABLE 5 - Average yield of Douglas-fir in New Zealand

Age	Recoverable volume	Log grades*			Residual vol.	MAI
		S1/S2	L1/L2	S3/S4		
(Years)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
10	103	14	3	60	26	10.3
20	229	26	5	129	69	11.5
30	410	47	8	260	95	13.7
40	609	136	16	370	87	15.2
50	843	337	23	395	88	16.9
60	959	445	28	390	86	16.0

* For explanation of Log Grade Codes see Appendix 1.

Source: Neumann and Perley (1992).

Douglas-fir growth rate data shown in Table 5 are averages for the whole country and stands that have been production-thinned have not been distinguished from those that have not. A thinned stand at age 60 would have a smaller recoverable volume than an unthinned stand (approximately 800–900 m^3/ha, compared with 1110–1200 m^3/ha) but the recoverable material would consist of larger diameter logs.

Fully stocked areas within a high performing stand at the head of Lake Ohau in Otago had a volume of over 2000 m^3/ha on 880 stems/ha. The mean annual increment (MAI) for this was close to 40 m^3/ha/annum, and basal area was 160 m^2/ha. In Nelson a 61-year-old stand had 1500 m^3/ha on a stocking of 560 stems/ha with MAI of 30m^3/ha/annum. At Karioi in the central North Island, at an altitude of 880 m, a stand had 1950 m^3/ha at age 52 years, while an older stand (105 years) near Geraldine, in Mid Canterbury, carried nearly 1700 m^3/ha at a stocking of only 104 stems/ha, representing an average volume of over 16 m^3 per tree.

At higher rainfalls in the South Island high country Douglas-fir productivity can be exceptional, being on a par with top radiata pine growth rates. Growth rates of more than 35 m^3/ha/yr have been recorded from stands on sites receiving rainfall exceeding 1300 mm, with productivity peaking at age 60 to 90 years.

Wood Properties

Douglas-fir has pale cream-coloured or nearly white sapwood and faintly orange-pink to yellowish heartwood. The heartwood is often reddish in the centre changing to yellowish on the outside and in some trees is entirely yellowish (Fig. 22). The outer limits of the heartwood are usually clearly distinguishable to the eye, but are sometimes irregular near the butt.

In contrast to radiata pine, which in New Zealand is essentially a "sapwood" species, Douglas-fir is a "heartwood" species. Even in fast-grown Douglas-fir trees the width of the sapwood band rarely exceeds 75 mm. Typically, at age 20 years, Douglas-fir logs contain about 20% heartwood; this proportion rises to about 60% by age 50 years. The heartwood has a moisture content of 40-50% as opposed to sapwood which has a moisture content of 100–140%.

Old natural stands can produce straight-grained clearwood with tight, uniform growth rings. In younger, plantation-grown Douglas-fir the earlywood/latewood boundary is abrupt and visually prominent, producing a coarse-textured sawn surface compared to some other softwoods. Typically, wood samples show about 50% latewood, although there may be variations due to environmental or silvicultural factors.

Fig. 22 - Heartwood boards of Douglas-fir, showing yellowish colour.

Physical properties

Wood density is a particularly important property for uses where stiffness and strength are required. As with radiata pine, however, the density of Douglas-fir varies between trees and between sites. This variation can be largely related to differences in seed source and in site. The average basic density of the sawn-timber is around 400 kg/m^3 for 50–60 year old stands of Douglas-fir, generally lower than for New Zealand-grown radiata pine. In Douglas-fir, the density of earlywood is usually less than 200 kg/m^3 and that of latewood, within the same ring, often exceeds 800 kg/m^3. Other within-tree sources of variation produce smaller changes in density. In New Zealand Douglas-fir, density usually decreases slightly over the first 5–10 rings from the pith, outside which it gradually increases with age by about 20–50 kg/m^3. This is less than the 100 kg/m^3 differential found between radiata pine corewood and outerwood, and the undesirable features of high longitudinal shrinkage near the pith, spiral grain and compression wood are also virtually absent in Douglas-fir.

Provenance trial data suggest that within a genetically uniform population there is a density decrease southwards (about 65 kg/m^3) between Kaingaroa and Rankleburn.

A ring width of about 3 mm or less (taken as an indicator of modest growth rate) was once believed to be critical for acceptable density levels in Douglas-fir. Later studies failed to confirm this, and trials on sawn timber have shown that the ring-width effect on density is very small. Currently, ring-widths in New Zealand grown timber range from 3 to 6 mm, approximately twice the average for old-growth stands and about the same as American second-growth stands.

Shrinkage in Douglas-fir (Table 6) is slightly higher than for radiata pine, but Douglas-fir is more stable in response to changes in humidity.

TABLE 6 - Shrinkage of New Zealand grown Douglas-fir* (from Cown, 1992)

Moisture Condition	Dimension	Shrinkage (%)
Green to 12%	Tangential	4.0
	Radial	2.8
	Longitudinal	0.2
	Volumetric	7.4
Green to Oven-dry	Tangential	8.1
	Radial	4.4
	Longitudinal	0.4
	Volumetric	11.9

* These data are similar to those published for old-growth North American Douglas-fir.

Machining and finishing

As sawn timber, Douglas-fir is less suitable than many other species for appearance grades, largely because of difficulties in machining and finishing. During sawing there is a tendency for the lower density earlywood bands to "pick out" leaving a ridged surface, and the wood is more splinter-prone than pine, especially near knots.

Douglas-fir requires care in nailing, having a tendency to split, e.g., at board ends. Latewood rings also tend to deflect nails, so some drilling may be necessary where precise application is required. However, nail-boards (gang-nail plates) in roof trusses for example, present no problem.

Mechanical properties

In North America, strength properties have been shown to be broadly constant from the fifteenth ring outwards, and independent of growth rate. Hence in second-growth stands the proportion of corewood (rings 1–15) is the dominant factor affecting wood characteristics. Studies in New Zealand have shown that timber strength in Douglas-fir, indicated by modulus of rupture (MOR), increased with narrowing ring width. Douglas-fir and radiata pine are variable species but a comparison of their average mechanical properties, based on small defect-free specimens, is given in Table 7.

Although wood properties are important in determining the usefulness of a species as a whole, in practice the single most influential factor affecting the strength properties of Douglas-fir is branch size.

TABLE 7 - Average mechanical properties of defect-free New Zealand grown Douglas-fir and radiata pine(1)

	Modulus of rupture (MPa) (2)		Modulus of elasticity (GPa) (3)		Compression (MPa)		Shear (MPa)		Hardness (N) (4)	
	Green	Dry	Green	Dry	Green	Dry	Green	Dry	Green	Dry
Douglas-fir	45	78	6.5	8.8	20	42	6.1	9.7	2189	3613
Radiata pine	39	90	5.8	9.0	16	38	5.1	12.0	2541	4180

(1) Bier (1983)
(2) MPa: megapascals
(3) GPa: gigapascals
(4) N: Newtons

Timber drying and preservation

Moisture contents of Douglas-fir heartwood and sapwood are virtually the same as those of corresponding radiata pine wood, and, as in radiata pine, drying rates are similar for the two types of wood. Air and kiln drying times needed for Douglas-fir are slightly shorter and the tendency to warp is markedly lower. However, the main difference between the species is the greater susceptibility of radiata pine pieces containing pith to twisting, supporting the reputation of Douglas-fir as a more stable species. Where distortion takes place it is most likely to be crook or spring, caused by knots and grain deviation.

There is a tendency for flat sawn timber to show surface checking, and this is most apparent in large sections used as exposed beams. Recommended kiln schedules for boards prescribe a milder treatment than for radiata pine to reduce the risk of checking. The checking of intergrown knots causes more problems than in radiata pine, and the larger the knot the more checks appear. This can affect appearance and finishing properties. Douglas-fir can be satisfactorily high-temperature dried, however.

Douglas-fir heartwood has a ground-contact durability varying from less than 5 years to up to 10 years. Out of ground-contact, service life is about the same as that of untreated radiata pine heartwood.

Douglas-fir sawn timber is suitable for use in buildings without preservative treatment. Freshly sawn, it is not as susceptible to sapstain as pine timber, although prolonged holding in a block stack will promote the development of stain and decay fungi if the timber is not treated with anti-sapstain chemicals.

The species is regarded as refractory for preservation because of the difficulty of getting chemicals into the heartwood and dry sapwood. It will not admit water-borne preservatives, and only the sapwood can be penetrated by oil-borne preservatives. Currently in New Zealand, oil treatments have been discontinued, under occupational safety and health provisions.

Uses of Douglas-fir

Old-growth stands of Douglas-fir in America have been a major source of structural timber, veneer, plywood and pulp and paper, the close-grown, uniform wood from large trees being the "Oregon" or "Oregon pine" of the timber industry.

Because of its good strength and stability New Zealand grown Douglas-fir is primarily suited for use as a structural and framing timber. It has greater fibre length than radiata pine, and a major advantage is that wood density and strength do not decrease near the pith, allowing framing timber to be sawn from much smaller logs including thinnings. When used above ground it does not need to be treated with preservative, so it can be sold to the end-user straight off the saw. Douglas-fir timber has a low moisture content and dries with little distortion. As well as its suitability for light timber framing, it is valued for internal exposed post and beam construction (Fig. 23).

Douglas-fir has been used for panelling (Fig. 24), the figure being sometimes enhanced by sand-blasting. However the boldness of the resulting patterns lends itself to special rather than general presentation.

Logs of Douglas-fir can be peeled satisfactorily provided that peeling is done more slowly than is customary for radiata pine.

As structural timber, Douglas-fir provides better recoveries than radiata pine. At its best it is an excellent timber for use as beams and columns. When stress-graded it can generally provide up to 60% timber suitable for structural and engineering purposes, and does not need drying and preserving for interior use.

Fig. 23 (far left) - Ceiling, and exposed beams of Douglas-fir.

Fig. 24 - Douglas-fir panelling.

Douglas-fir can be used as a source of wood chips for the manufacture of both reconstituted boards and pulp. Because the darker colour of Douglas-fir is less desirable than that of radiata pine, chips of the two species are best kept separate. Although it is technically possible to use 100% Douglas-fir in chipboard and medium-density fibreboard, the proportion is normally restricted to about 15% to control the colour of the product.

Douglas-fir is an important pulpwood species in the Pacific Northwest region of the USA. It is especially valued for the improvement it brings in tear strength of paper products when mixed with pulp made from other species. Although its use as pulpwood in New Zealand is limited, kraft pulps are easily prepared from New Zealand-grown Douglas-fir, at slightly lower yields than radiata pine. It has a high tear index relative to radiata pine. The chief constraint on its use is the high bleach requirement arising from its dark heartwood colour.

Douglas-fir is not normally used by itself for mechanical pulp because of its poor brightness. Small amounts of it can be tolerated in sawmill residues used for refined pulp production. Up to 30% can be added to radiata pine without appreciably lowering brightness.

In New Zealand, very little interest has been expressed in the use of Douglas-fir in veneer and plywood manufacture, despite the fact that it is the mainstay of the Pacific Northwest industry. Research trials have shown that local logs peel poorly and, compared with radiata pine, veneer characteristics are very variable due to the earlywood/latewood contrast. However, it is possible that better results could be obtained with appropriate adjustments, e.g., to knife angle, feed speed and pre-heating schedules.

Douglas-fir has a well established role as an amenity and shelter species. Where there is no browsing, open-grown specimens often branch almost from ground level and Douglas-fir hedges and shelterbelts can provide a solid screen within a few years of planting. Older open-grown specimens can be imposing and attractive shade trees, the rich, uniform colour and pyramidal crown providing additional scope for species contrasts and landscaping effects. Young Douglas-fir is a popular Christmas tree on account of its shape and fragrant foliage.

Douglas-fir firewood is clean, fairly fast-burning and slightly superior to radiata pine owing to its lower moisture content and higher wood density. A drawback is its tendency to spit and spark, and for this reason it is safer used in enclosed rather than in open fireplaces.

MARKETING OF DOUGLAS-FIR

Douglas-fir has an excellent reputation as a general purpose structural timber on both domestic and export markets. The long established reputation of "Oregon pine", the commercial trade-name for timber originating from the native stands in North America, confers a key marketing advantage to all Douglas-fir timber. Huge shortfalls in the supply of Douglas-fir to traditional markets are already occurring because of reduced availability in the American Pacific Northwest due to increasing conservation pressure to preserve habitats for wildlife such as the spotted owl. Less than 18% of the original old-crop Douglas-fir resource remains to be harvested. In the future the market will be satisfied by timber from "second-growth" forests to which New Zealand plantation-grown timber is similar in quality.

Douglas-fir exports from New Zealand include both sawn timber and logs (Fig. 25). The three largest markets for New Zealand exports of sawn timber from 1991 to 1993 were Australia, New Caledonia and Japan respectively, representing an annual export volume of almost 70,000 m^3. Douglas-fir is also currently the major softwood log species imported into the

Fig. 25 - Douglas-fir logs for export to the USA.

Japanese market, comprising 23% of total (hardwood and softwood) log imports and 36% of the softwood log imports. Most of this timber still originates in North America. New Zealand recently adopted the same log-grading rules as American producers and is making a significant contribution to supplies.

Current exports of unprocessed New Zealand logs to Asian markets including exports to China confirm the high relative value of Douglas-fir. Wharf gate prices for unpruned structural grade Douglas-fir logs are approximately the same as current prices paid for pruned radiata pine logs. Size, straightness and small knot diameter (2–3 cm, with provisions for up to 4–6 cm in certain grades) are the requirements for such high quality logs.

FUTURE ROLE OF DOUGLAS-FIR IN NEW ZEALAND

Douglas-fir has a well established reputation as a commercially viable softwood species suitable for a variety of New Zealand sites. However, its current reputation is based on the end-product of a largely restricted provenance range (Washington and Oregon), tended and managed in the past according to methods which may no longer be economically justified. In future, the species needs:

- The development of a sound genetic improvement programme.
- An improved understanding of the effects of site and silviculture on stand growth and quality.
- Inclusion of Douglas-fir into the integrated computer-based modelling system "STANDPAK" for evaluating management options.
- The acceptance in the international marketplace of a reduced quality product compared with the "old growth" Douglas-fir.

Genetic Improvement

Future success with Douglas-fir depends on improvement resulting from a broadly based and flexible breeding programme. This will involve recurrent selection, mating and testing among the best adapted and most productive genetic strains available. Proposals for a comprehensive breeding plan have been developed by the Douglas-fir Research Co-operative.

Breeders face some difficulty with Douglas-fir in that good seed years occur somewhat irregularly. Research is needed into flower-promoting techniques to assist crop continuity in seed orchards. Early results of gibberellin application in the Waikuku Orchard are encouraging (Fig. 26).

Vegetative propagation provides a means of increasing the number of plants that can be obtained from small valuable seed crops. Research into methods of vegetative propagation for Douglas-fir is at an early stage in New Zealand, but North American work has shown the practicability of producing rooted-cuttings. However, at present production of cuttings takes three years and the main challenge is to reduce costs.

Douglas-fir has been propagated in New Zealand by tip-cleft grafting. Although some plants have suffered from stock/scion incompatibility, recent grafting for the Proseed Ltd. seed orchard, carried out in Canterbury, has been largely successful. Climate may be an influential factor.

Fig. 26 - Bagging of female cones of Douglas-fir after gibberellin application on ramets grafted 2-4 years previously, Waikuku seed orchard, North Canterbury.

Revised Management Regimes

Economic pressures now require that New Zealand Douglas-fir should originate from less conservative management regimes (shorter rotations, faster growth rates, wider spacing).

Since about 1970, Douglas-fir silvicultural schedules have prescribed rotation lengths shortened to 40-50 years. The aim is to maximise growth rates while restricting knot sizes to comply with requirements set for good structural timber. As yet the new regimes are largely speculative as there are few mature examples which can be evaluated by sawing. Also, revised schedules have not yet been fully implemented, so there is still scope for local changes. A comprehensive database relating growth and yield to site and treatment, is being compiled as part of the work programme of the plantation management group at the New Zealand Forest Research Institute and will help to guide future Douglas-fir management.

The End Product

Present indications are that there will be a sustainable and probably increasing overseas market for high-quality structural grades of Douglas-fir sawn timber or logs exported from New Zealand. In order to demonstrate that standards of strength and stiffness are being maintained the inclusion of machine stress grading as an integral part of sawn timber production may be worth considering. Although logs cannot be stress-graded, their association with routinely stress-graded sawtimber from the same New Zealand sources is likely to benefit marketability.

Douglas-fir Research Cooperatives

Recent high log prices, coupled with interest in the Pacific Northwest in intensive management of Douglas-fir plantations, have resulted in a cooperative research programme between NZ FRI and the US Forest Service, aimed mainly at evaluating the links between silviculture (including pruning), and stand yields and quality. A Douglas-fir Research Cooperative has also been formed, centred at the NZ FRI and supported by New Zealand growers. A comprehensive research programme covering diverse topics such as nutritional requirements, herbicides, breeding, silviculture and wood properties is currently underway. Detailed information can be expected to result over the next few years, particularly relating site, silviculture, and genetics to timber quality and yield.

Douglas-fir, second only to radiata pine in commercial importance in New Zealand, grows well over much of the country and can outperform radiata pine on some, usually higher altitude sites, as it is less affected by wind and snow damage. Older stands of Douglas-fir have yielded high volumes of structural grade sawn timber, and export logs. Future plantings are expected to be managed under revised tending schedules involving shorter rotations and increased growth rates, and using vigorous provenances developed within an ongoing genetic improvement programme.

SEED USERS' GUIDE

Seeding in Douglas-fir

Abundant seed crops occur at irregular intervals in Douglas-fir, from 2–10 years or more apart. Light to medium crops occur in the intervening years with usually one crop failure between the heavy crops.

Future seed shortages may be partly offset by the use of vegetative propagules (cuttings). However, good seed years provide an opportunity to collect large quantities of desirable Douglas-fir seed and store the surplus.

A: Collection, extraction and handling of Douglas-fir seed

Age of first flowering:	7–15 years, depending on site
Seed availability:	15–20 years
Pollen production:	Late September to late October, peaking in early October
Fruit maturation period:	Four months
Seed collection:	February–March
Periodicity of crop:	2 to 10 years or more. Natural crop-periodicity very irregular. In Canterbury best seed crops occur every 1–3 years
Harvesting:	Cones picked from standing trees using branch hooks
Mature cone recognition:	Mature cones show brownish or purplish tinge and cone bracts turn brown. Seed coat should be golden brown with wing of same colour detaching intact from its cone scale. Seed should be firm and non-milky when cut
Seed extraction:	Do not leave cones to heat in closed bags. Spread out on tarpaulins to air-dry as soon as collected. Kiln-dry cones to finish if necessary
Seed recovery:	550 to 1750 grammes per 100 litres cones. Average 20–30 sound seeds per cone. Generally higher in South Island than in North Island
Seed/kg:	90,000 to 100,000
Storage conditions:	Airtight containers
Storage duration:	10–20 years at 4°C and 6–9% moisture content
Stratification:	Water-soak overnight and refrigerate moist at 5°C for 5 weeks
Expected germination:	Ranges from 46–77%, but usually 75% or better; this equates to 75,000–85,000 viable seeds/kg

B: Nursery practice

General:

- Light, friable nursery soil is preferable: Douglas-fir is intolerant of poorly drained or poorly aerated soils, in which it may become susceptible to root infections such as *Phytophthora* and in which natural mycorrhizae may not thrive.

- Douglas-fir seedlings are very vulnerable to root-rot when growing in containers.

- In the nursery bed Douglas-fir seed should not be sown deeper than 4-6 mm (i.e., it should be covered very lightly), as hypocotyls are short. Large grades of seed usually germinate best.

Bare-rooted systems

Seed is precision-sown at the equivalent of 14–16 viable seeds per metre of drill, aiming at an average spacing of 10 cm between seedlings. Drills should be at 15–18 cm centres.

1 year old stock(1/0): Douglas-fir has often been raised as 1-year-old stock, especially in North Island nurseries. For this, early sowing (in September) is necessary, followed by a good growing season, enabling stock to reach adequate height (20–30 cm) and to be consolidated by undercutting and wrenching before the winter. However, in poor seasons there is a danger that plants may not be sturdy enough, or that delayed germination may reduce stock numbers. Therefore, although it has the lowest production costs, 1-year-old stock is not widely favoured, especially if slower-growing provenances are involved or if prospective planting sites are severe or exposed.

2 year old (2/0) and 3 year old (3/0; 2/1) stock: Two-year-old stock is the most routinely used Douglas-fir stock in both North and South Islands.It is usually grown to a height of 40-60 cm, with root-collar diameters of 10–12 mm. Initial treatment is as for 1-year-old stock but trees are undercut at 8–10 cm depth at the start of the second growing season. Trees may be conditioned by further undercutting in late summer/early autumn and wrenched at 4–6 week intervals. Lateral pruning is usually carried out after the second wrenching. Periodically, in both North and South Islands, large (70–80 cm) 3-year-old stock has been grown, usually to order, for planting on difficult or weed-prone sites. In the production of large planting stock (2-3 year-old) it is essential to ensure a good root-shoot ratio. Top-heavy stock should be avoided.

1½ year old stock (1½/0): A method now being increasingly favoured. Seed is sown in December/January in the South Island but not until February in the North Island. The stock is deeply undercut (i.e., to cut the taproot only) before the first winter. Further undercutting is done in mid or late summer. A danger in this system is vulnerability to frost-lift of the (inevitably small) seedlings during the first winter.

Two year transplanted stock (1/1): Little interest has been shown in New Zealand in systems commonly used in North America which include sowing Douglas-fir thickly in drills in the first season and lifting, grading and lining out for a second season in the nursery bed.

Containerised systems

Containers have not generally been used for Douglas-fir planting in the past, As yet this approach to planting stock production of Douglas-fir is experimental.

Root-trainers; "split" containers: Production takes one year, and root and shoot size are restricted. Seed is direct-sown into containers, thus minimising wastage and fertiliser application is easily controlled. There is a need to guard against root-rot, to which containerised Douglas-fir is prone. Methods of introducing mycorrhizae into the root system need to be devised.

"Plug" systems: Most investigation of these systems has occurred in North America, however there is recent and increasing interest in their use in New Zealand. Seed is sown directly into containers in December/January, or even later, in February/March, and the resulting "plug" stock lined out in the nursery bed in the following spring. The logistics of handling large numbers of "plugs" in the field have not yet been explored, but the system appears to have several advantages. There is a saving in seed, and it is presumed that sturdiness can be fostered in transplanted stock. Stock should also be able to acquire suitable mycorrhizae from the soil of already inoculated nurseries. However, the "plugs" may be vulnerable to fluctuations in moisture until well settled in the nursery beds.

C: Recommended Seed Sources

Recommended seed sources consist of the seed stands being developed in New Zealand forests to supply commercial quantities of seed of strains of Douglas-fir which have shown promise in local plantations.

The strains offered in existing seed stands are:

1. Californian strains: Origins Fort Bragg; Swanton. Characterised by fast growth rates, especially at low elevations or relatively sheltered sites, but potential may extend to more severe sites as well.

2. Ashley strain: Ancestry believed to be coastal Oregon. Descended from a small seed import in 1875, grown initially in the Tapawera district south of Nelson. Later planted in Golden Downs Forest and Ashley Forest, Canterbury. Has proved vigorous and well adapted over a wide range of sites.

3. Beaumont strain: Primarily of Washington ancestry, and of similar type to early Kaingaroa plantings. Characteristic of well-formed stands in Otago and Southland, especially in the Tapanui district of west Otago; currently recommended as a suitable strain for exposed, higher elevation sites in southern areas. In the future may be superseded by better strains demonstrated by seed-source trials or trials of the new breeding population.

Productive seed stands

Seed Stand Number	Origin/strain of Douglas-fir	Locality (Forest/Cpt)	Year planted	Area (ha)
RO26	Fort Bragg	Rotoehu,55	1960	4.0
RO42	Swanton	Rotoehu,55	1972	10.9
NM3	Fort Bragg	Golden Downs, 114	1959/60	5.3
NM6	Swanton	Golden Downs, 75	1977	4.5
NM9	Ashley (3rd gen.)*	Golden Downs, 63	1968	7.3
NM10	Ashley (3rd gen.)	Golden Downs, 214	1968	5.2
CY28	Ashley (2nd gen.)	Eyrewell, Main Race Road	1969	3.0
CY31	Ashley (2nd gen.)	Ashley,150	1971	17.0
CY33	Ashley (2nd gen.)	Mt. Thomas,1/1	1973	5.3
SD5	Beaumont	Beaumont,17	1952	5.5

* The original (i.e., 1st generation) seed stand, CY22, was planted in Cpt 12, Ashley Forest. It was felled in 1989.

Seed stands (potential or under development)

Origin/strain of Douglas-fir	Locality (Forest/Cpt)	Year planted	Area (ha)	PSP No.
Fort Bragg	Kaingaroa, 1141	1981	48.3	RO 2054/1
	Kaingaroa, 1132	1981	7.9	RO 2054/1
Bandon* (coastal Oregon)	Rotoaira (13 Cpts)	1975–6	27.4	RO 2054/4
Swanton	Ngaumu, 392	1972	7.3	Wn 357
Ashley (2nd gen)	Eyrewell, 46/5	1982	18.5	CY 584/3
Mixed Californian**	Pomahaka, 201	1984	13.8	

* 13 separate areas of 1–5 hectares each

** Compounded from 22 plus trees ex provenance trials. Currently the most advanced seed source of Californian origin available.

A number of outplantings made with seed collected from some productive seed stands, will be suitable as sources for further collection as they attain seed production age. Identification may be made through their seedlot numbers, as shown opposite.

It is expected that in good seed years the bulk of routine seed supplies will be obtained from these well-adapted sources, or from descendant stands perpetuated by simple mass selection, until overtaken in the future by seed or propagule supplies of superior quality from the breeding population generated by the breeding plan.

Seed of Douglas-fir is available from:

Proseed New Zealand Ltd.
Private Bag 3020, Rotorua, New Zealand

Tasman Forestry Ltd. are seed-stand owners and prospective suppliers of Douglas-fir seed.

Seedlot numbers of good future seed sources

Strain	Parent Seed Stand	Descendant seedlot numbers		
Fort Bragg	RO26	R/2/78/34	2/2/86/42	
	NM3	NN/0/78/10	NN/2/79/6	NN/2/82/2
Ashley	CY22	C 66/518	C 69/B22	C 73/B22
		CY B/75/22	CY B/75/23	CY B/76/8
		CY B/6/9	CY B/78/20	CY B/79/22
		6/5/81/5	6/2/82/7	6/5/84/18
		6/5/86/14		
	NM9	4/82/3 *	4/2/84/7	
	NM10	4/82/3 *		
	CY28	6/2/82/14	6/2/84/14	89/291
		6/2/86/12	6/2/85/14	90/651
Beaumont	SD5	S 70/1084	SD C/75/12	SD C/76/16
		SD C/79/10	SD C/79/22	7/2/81/21
		7/2/82/5	7/0/83/4	7/0*83/5
		7/2/84/4	7/2/85/6	7/2/85/13
		7/2/86/6		

* Indicates combined collection

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ACKNOWLEDGMENTS

The authors are grateful to M.D. Wilcox, R.N. James, N.J. Ledgard, R.D. Burdon, and C.E Ecroyd for helpful comments on the text. They also especially thank L. Knowles and I. McInnes (silviculture), N. Davenhill (weed control), D. Cown (wood properties) and G. Young, T. Thorpe, and W. Brown for useful information. Maps and graphics in the bulletin were drawn by P. Neville, and editing and layout design were done by L.J. Whitehouse. The cover was designed by T.J. McConchie. Photographs were taken by J.H. Barran (Frontispiece photos, Figures 9-15, 22, and 25), H. Hemming (Fig. 4, 23, and 24), N. Ledgard (cover photo, Figures 16, 17, 19 and 20), L. Knowles (Fig. 21), M. Menzies (Fig. 6), J. Johns (Fig. 8), G. Vincent (Fig. 26), D. McLuggage (Fig. 5) and D. Blake (Fig. 18).

APPENDIX: LOG GRADE SPECIFICATIONS

Yields have been defined in terms of five standard log categories: P1/P2, S1/S2,L1/L2, S3/L3, R (Log grade R includes R, L4 and S4 categories).

Log Grade Specifications

Log Grade	Pruned/ Unpruned	Small-end diameter (mm)	Largest single branch (mm)	Sweep Class #	Minimum internode length index*
P1	Pruned	400+	n.a.	1	n.a.
P2	Pruned	300-399	n.a.	1	n.a.
S1	Unpruned	400+	6	1	n.a.
S2	Unpruned	300-399	6	1	n.a.
S3	Unpruned	200-299	6	1	n.a.
S4	Unpruned	150-199	6	1	n.a.
L1	Unpruned	400+	7–14	1	n.a.
L2	Unpruned	300-399	7–14	1	n.a.
L3	Unpruned	200-299	7–14	1	n.a.
L4	Unpruned	150-199	7–14	1	n.a.
I	Unpruned	300+	7–14	1	0.6
R	Unpruned	100+	n.a.	2	n.a.

* Internode length index is the sum of lengths of the internodes of 0.6 m or longer expressed as a fraction of the log length.

sweep is defined as the maximum deviation from straightness along the length of the log (see below).

Maximum Possible Sweep (by sweep class)

Sweep Class	Log Length (m)			
	< 3.7	3.7 - 4.8	4.9 - 7.6	> 7.6
1	d/8	d/4	d/3	d/2
2	d	2d	3d	4d

Where d = diameter at the top of the section being assessed for sweep.
Source: Whiteside and Manley, 1987.