ARTICLES

SNOW DAMAGE

IN PLANTATION FORESTS IN SOUTHERN NEW ZEALAND

By D.W. Guild*

ABSTRACT

In May 1983 severe snow damage was sustained by plantation production forests in Otago and Southland, New Zealand. Snow in New Zealand tends to be denser (wetter) than in continental climates, and the principal plantation species — radiata pine — is not well adapted to shed snow. Nevertheless, on all but the most snow-prone sites, heavily pruned and thinned radiata pine planted at wide initial spacing appears to be capable of producing an acceptable final crop. Good control of brush weeds is essential to avoid unnecessary snow damage in young stands, and there is potential for a further reduction by breeding for multinodal branching and high wood density. On the worst sites, the forest manager has the choice of leaving the sites unplanted, planting them in radiata pine and accepting the damage, or planting them in a more snow-tolerant species such as Douglas fir or Eucalyptus delegatensis.

As in other parts of New Zealand, plantation forestry in the southern region — Otago and Southland (Fig. 1) — has expanded considerably in the last two decades, with 110,000 ha having been established. As new planting continues toward a target estate of 110,000 ha by the year 2000, more plantations are likely to be established close to the upper altitudinal limit for economic forestry. For its own production forests the N.Z. Forest Service has set this limit at 600 m a.s.l. for the main forestry areas of south east Otago and Southland where radiata pine (*Pinus radiata*) is the principal species, and 750 m for Central Otago where Douglas fir (*Pseudotsuga menziesii*) and Corsican Pine (*Pinus nigra var. laricio*) are the principal species.

Although snow damage in plantation forests in this region is by no means a new phenomenon, recent snowfalls have caused considerable damage well below these altitudinal limits. A particularly damaging snowfall on May 17-18, 1983 led to a discussion workshop in Invercargill on October 20, 1983. The findings of the workshop and a questionnaire to forest owners are reported here.

IDENTIFICATION OF SNOW PRONE SITES

All parts of the southern region can expect a snowfall at least once a year, though these are seldom heavy or prolonged at low altitudes. At the other extreme, heavy snowfalls are common in the mountainous parts of the region where permanent snow fields and glaciers occur in places above 2000 m.

In the valleys and basins of Central Otago (140 — 350 m a.s.l.) snowfalls average five to ten days per year (de Lisle and Browne 1968) while in coastal Otago and on the Southland Plains (0 — 70 m a.s.l.) the average is one to five days per year (N.Z. Meteorological Service 1973). On the hill country of coastal Otago and Southland, where most of the plantation forests in this region are situated, the average is 10 — 20 days per year in the 200 — 400 m altitude range, but there is little information available for the 400 — 600 m level which covers the rest of the plantation forestry sites.

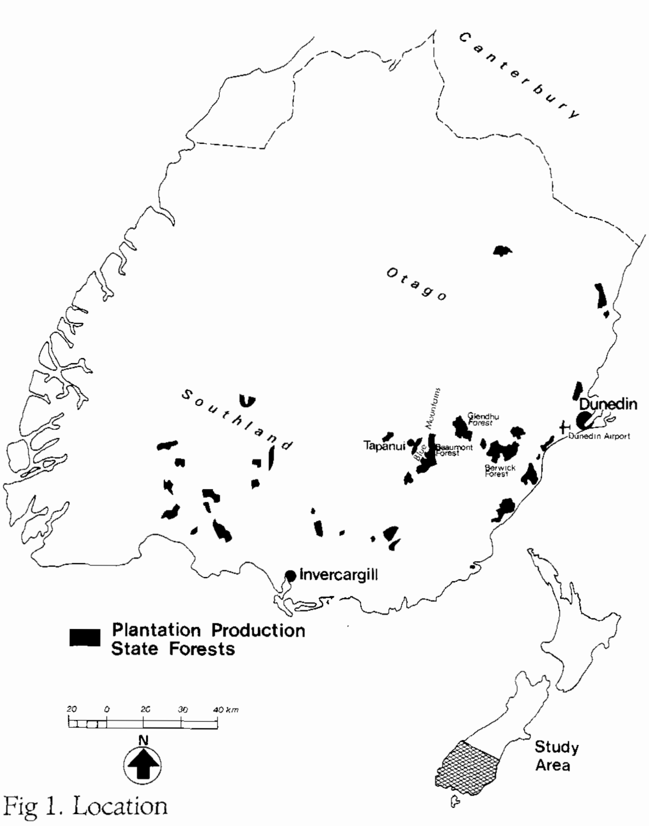

Fig 1. Location

Snow has fallen in all months except January. In winter, with an outbreak of cold air from the south, Southland and coastal Otago may be snow covered down to sea level. Most snow is brought by storms from the south-west for coastal Otago and Southland, but north-westerly storms are not uncommon in inland Otago and northern Southland. In potential production forest areas snowfalls tend to occur between May and November, inclusive.

The N.Z. Meteorological Service (pers. comm.) noted that the snow depths that fell in the May 1983 storm were not unusual and the wind gusts and wind runs recorded at Dunedin Airport were not remarkable — highest gusts being 43 knots and 39 knots on May 17 and 18 respectively. Wind run values for Lake Mahinerangi were similarly unremarkable. What was unusual was the long duration of strong winds. At

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Dunedin Airport mean wind speeds were above 20 knots for 34 consecutive hours, which is unprecedented in a record of 13 years. The same storm, when it hit Wellington, had a record number of consecutive hours of 40 knot winds from the south. The only other storm which approached this duration occurred in 1947.

Two farm foresters living on widely separated and exposed properties — John McKay of Montana near Tapanui and Graham Flett of Skilbister near Berwick Forest — both reported a lack of wind in their areas where heavy snow fell. These observations are perhaps significant in that they both live at altitudes above 300 m, which are higher than most climatological stations and forest headquarters from which such observations are usually made. They probably reflect the variability that can occur in such storms.

Precipitation recordings taken at the Forest Research Institute hydrological trials at Glen Dhu Forest and Berwick Forest indicate snowfalls in excess of 0.3 m (Table 1). This data may include rain because no separate snow recording instruments were available at the time. However, the precipitation recorded corresponds to a period of low temperatures (mostly less than 1 °C) as recorded on a hydrothermograph at the Glen Dhu meteorological site.

TABLE 1: PRECIPITATION RECORDED MAY 17-19, 1983 (INCLUSIVE) AT HYDROLOGICAL TRIAL SITES

Location	Altitude (m)	Precipitation (1) in Water Equivalents (2) (mm)	Estimated Depth of Snowfall (3) (m)
Glen Dhu Upper Site	670	91	0.303
Glen Dhu Met. Site	625	93	0.310
Glen Dhu Lower Site	515	115	0.383
Berwick Interception Study Site Cpt 89	280	133	0.443

(1) Precipitation recorded may include rain as well as snow.
(2) Water equivalents = melted snow and/or rain.
(3) Assuming a snow density of 0.3 g/cm³

A questionnaire sent to the managers of all major plantations in the region prior to the workshop elicited 18 replies. Those who responded expected 42,000 ha (38%) of their current forest area of 110,000 ha to be damaged by heavy snow at some time in the life of the crop. However, in the winters of 1982 and 1983 only 550 ha (0.5%) were estimated to be heavily damaged by snow. In reviewing climatic damage to forests of the Tapanui District, Chandler (1968) expected an unspecified proportion of Tapanui Forest to suffer severe snow damage at least once every decade. In any one season, damage is most likely to be very localised, with a few sites in a few forests being damaged.

The relation of damage to altitude in the 1983 storm varied markedly from forest to forest. Damage was reported as low as 100 m but the most common lower limit was about 350 m. There is no clear contour within the economic forestry zone above which damage is likely as other site factors are involved.

Damage occurred on all aspects, but generally the greatest damage occurred on lee aspects where snowdrifts accumulated.

Where snow is brought by south-westerly winds, north-west, north and north-east aspects generally sustain greatest damage, while north-west storms cause snow damage to south-easterly aspects. Damage also occurred on exposed ridges, and on exposed aspects where strong winds accompanied or followed the snowfall.

CHARACTERISTICS OF SNOW AND MECHANISM OF SNOW DAMAGE TO TREES

New Zealand's climate is strongly influenced by its occurrence in an ocean in the mid-latitude, westerly wind zone of the Southern Hemisphere. These winds have had ample opportunity to become moisture laden, and so humid conditions are common. In addition, the passage over the ocean has a moderating influence on air temperature. Consequently snowfalls in New Zealand are usually wetter and therefore heavier than the powder or dry snow common in continental regions.

Morris and O'Loughlin (1965) found that, at 1400 — 1700 m altitude in the Craigieburn Range in Canterbury, NZ, the density of freshly fallen snow varied from 0.11 to 0.20, and averaged 0.15 g/cm³. The lower end of the range approaches European and North American values. The higher densities, even for fresh snow, are probably a reflection of the comparatively mild winter conditions experienced in the region — certainly there are no instances of recorded densities as low as 0.01 g/cm³, a figure not exceptional for Scandinavia. Gillies (1964), in his description of snow studies of the high plateau country of inland Otago, records a density range of 0.10 to 0.50 g/cm³ with an average of 0.30. In reporting on the meteorological aspects of the big snow in Canterbury 1973, Tomlinson and Edie (1976) noted that since about 1939, the reports of snowfalls have improved quantitatively and it has become apparent that our heaviest snowfalls at lower levels have a large water content. The limited reports available reveal a complex situation but generally speaking the deepest snowfalls at low levels have a high specific gravity of about 0.3 g/cm³ while at levels above 1000 m the specific gravity is commonly 0.1 to 0.2. Most snowfalls that occur in plantations in New Zealand, then, would be of higher average density than that experienced in Europe or North America. Thus trees would be subjected to heavier snow loadings than their northern hemisphere counterparts.

The amount of snow that will adhere to branches depends mainly on its temperature and consistency, but also on the slope and position of the branches, the force and direction of wind, and various other factors (Peace 1962). Very cold snow usually falls in small particles which do not readily cohere, whereas snow nearer the melting point falls in larger flakes which can build up on twigs and branches to a surprising degree. In a study of snowstorms in the Craigieburn Range between 1964 and 1968 O'Loughlin (1969) estimated that mountain beech forest growing at 900 — 1350 m altitude was supporting 250 tonnes of snow/ha in its canopy.

While wind can easily dislodge low density snow from branches, the combination of wind and high density snow can be much more damaging. With wind, this 'sticky' snow is shaken until it envelops the whole surface area of foliage and branches and the surface area are encapsulated by snow, the total surface area being some 2.3 times greater than the projected area (Nordmeyer pers. comm.). If this in turn freezes on the tree, large volumes and weights can accumulate. Rime ice develops when supercooled water (or moist snow) strikes the surface which is itself below freezing point. Once the process of encrustation develops then the surface areas increase thereby adding to the weight of water retained as ice.

Assuming that 40 mm of water equivalent falls as wet snow in a storm, the weight of snow on average (i.e., not accounting for drifting) falling on a forest is 400 tonnes/ha. Assuming that 50% of this is caught by the foliage and branches, the extra weight to be carried by the trees is 200 tonnes/ha. The weight of branches and needles carried by thinned stands of 8 to 29-year-old radiata pine in Kaingaroa State Forest in the central North Island is 7 to 56 tonnes/ha of dry matter. (Madgwick et al 1977; Webber and Madgwick, 1983). The tonnage of snow that could be deposited on a forest of radiata pine from a 40 mm water equivalent storm, then, amounts to several times the dry weight of the branches and needles, and rimeforming conditions would further increase this.

Vertical forces on a symmetrical tree would tend to cause branches to bend or snap at their weakest point. However, forces are not always vertical. On slopes, the distribution of branches around the stem is not symmetrical. A disproportionate amount of branch and foliage biomass occurs on the downhill (open) side of the tree. Likewise, wind will cause a change in the angle of the forces away from the vertical. Therefore there is an interplay between wind direction, snow accretion on surfaces, and the forces which tend to bend the tree.

On the windward slope the wind force will tend to counteract the bending downhill which follows from the weight distribution on downhill branch systems. On lee slopes, any wind will carry the bending forces along with the added weight; the forces generated then are considerably greater than simply the weight of the branch systems plus the snow. Since the forces developed are dependent on the mass of the canopy and its snow loading combined with the acceleration due to wind, even short gusts of wind are likely to cause severe damage once snow loadings reach a critical level. However, there is no firm basis for predicting the critical mass of snow loading which can be tolerated by radiata pine.

SNOW DAMAGE ON PLANTATION TREES

Types of Damage

The types of mechanical damage that trees can sustain from snow are as follows:

1. Branch bend. The mildest form of mechanical damage is bent branches. This type of damage is of no consequence to normal production forestry and is frequently observed after all but the lightest snowfalls.
2. Branch breakage. When the snow load exceeds the strength of a branch it will break. In radiata pine large diameter branches are particularly vulnerable. Breakage often occurs within the stem as the branch is literally torn out of the stem, leaving a conical-shaped hole (Fig 2). This type of damage can provide entry points for damaging fungal diseases, and, of course, leaves a wood defect in its own right. Nevertheless, the significance of this form of damage is relatively minor except that it can lead to stem break at the weakened point.
3. Stem bend. Driving winds accompanying the snow, and a symmetrical crown, can cause stems of young trees and weaker older trees to bend when the load exceeds the strength of the stem. Most seedlings and small trees will recover naturally from stem bend, but larger trees may not. There appears to be a strong relationship between the height/diameter ratio within a species, and its ability to withstand snow loads without bending. Cremer et al (1983) suggest, from experience with heavy snow damage in Australian plantations of radiata pine in 1981, that stands with a height/d.b.h.o.b. ratio (for the 200 largest diameter trees/ha) below 70 may be regarded as safe from both wind and snow damage, and those above 80 as vulnerable. The risk of snow damage is increased, irrespective of the height/diameter ratio, if many vulnerable trees are present and the spacing is so close that trees which fall under their own load bring down their neighbours. There has been no local research to confirm the Australian work. However, observations suggest that stem bend causes significant losses both from the permanent damage in older trees and from the chain reaction that can be caused by a few weaker trees.
4. Stem break. In severe conditions, snow and wind loadings can cause stem break in trees of any age. However, it is unlikely in seedlings where the stem tissue remains very supple for the first year or so after planting. In young trees breakage often occurs near the base of the green crown, and often is associated with a node (Fig 3). This leads to a complete loss of the stem. Permanent defects may result from leader breakage; fresh spring leader growth of radiata pine is particularly susceptible to damage from late

Fig 2. Snow damage to radiata pine branches.

Fig 3. Severe snow damage in radiata pine showing breakage at the base of the green crown and uprooting. (Photo: A. Flux)

snowfalls. Breakage in older trees often occurs close to the merchantable diameter limit of 10 — 15 cm. In such cases decay may penetrate the utilisable portion of the tree unless the trees are rapidly salvaged. Stem break can cause high economic loss in young or old stands when salvage is not possible.

5. Uprooting. In severe conditions, trees and seedlings can be uprooted by the direct force of wind and snow exceeding the root strength. Alternatively snow creep may carry trees along with it as it moves downslope. As with stem break, the effects of uprooting are usually devastating unless the material can be salvaged. In some cases, seedlings and small trees may survive (as 'toppled' trees) and these may recover to an upright position with or without severe butt sweep.

The answers to the questionnaire suggested that tree toppling and stem bending occurred in young radiata pine stands up to about age six (4-6 m stand height); stem breakage was more frequent than bending from about age 6 — 12, (4-6 m to 9-12 m stand height) with breakage often occurring at the lowest remaining whorl; and branch snap is most common in older stands. From age six on, malformed trees, particularly those with multiple crowns or large branches, suffered most damage.

The health of seedlings may deteriorate if there is prolonged burial and flattening under heavy snow packs and this is especially evident in hollows.

Comparison of Species

In 1983 radiata pine suffered the most damage, but it is also the most widely planted in snow-prone areas. Muricata pine (*P. muricata*) was generally found to be no more resilient (and perhaps less so) to snow damage than radiata pine. Those species reported to be least damaged by snow were Corsican pine, Douglas fir, European larch (*Larix decidua*), ponderosa pine (*P. ponderosa*), lodgepole pine (*P. contorta*) and eucalypt species, especially *E. delegatensis*. Of these Douglas fir and *E. delegatensis* have the most economic potential. The questionnaire revealed that there are differences in snow tolerance between species and that considerable variation occurred from place to place.

Hughes (1968) noted that the following species sustained negligible damage from the 1967 snow in Canterbury:

Corsican pine, ponderosa pine, Jeffrey's pine (*P. jeffreyii*), Norway spruce (*Picea abies*), sitka spruce (*P. sitchensis*), Douglas fir, Wellingtonia (*Sequoiadendron giganteum*), Lawson cypress (*Chamaecyparis lawsoniana*), western red cedar (*Thuja plicata*) and deodar cedar (*Cedrus deodara*).

The Influence of Silvicultural Treatment

Because uneven snow loads put undue strain on root systems, trees that have been poorly planted, or where root/shoot ratios are out of normal balance, are likely to suffer uprooting or toppling. This applies also to some site cultivation methods and possibly to fertilisation.

There is some evidence that young stands planted at wider spacing (say 1000 stems/ha or less) suffered less damage than those planted at closer spacing (1600 stems/ha or more).

Contour planting on steep sites appeared to aggravate snow damage. Snow built up against young trees on the uphill side, and the weight of snow, possibly combined with snow creep, pushed them over.

Brush weeds such as gorse (*Ulex europaeus*) and broom (*Cytisus scoparius*) competing with young trees will increase snow damage. These fastigate brush weeds lean onto trees when snow builds up on them, which results in stem lean, toppling or uprooting. This phenomenon has also been reported by Hughes (1976). Furthermore, trees growing in competition with brush weeds are more spindly than normal and are thus easily damaged by snow.

In general, intensively tended stands — heavily thinned and pruned at an early age — were less damaged than untended stands, confirming similar findings in Canterbury after the 1973 snow storm (Hughes 1976). However, on extremely snow-prone sites tending made no difference as stands are destroyed indiscriminately.

Pruning reduces the surface areas which will retain snow. It removes the lower branches which are also the longest and largest and therefore those most likely to be damaged. However, pruning shifts the likely point of stem fracture up the tree to the new base of the green canopy where the stem is smaller in diameter and weaker. In general, pruning provides a net benefit in terms of reducing the amount of snow damage.

Thinning, as usually practised in radiata pine in this country, occurs well before a critical height/diameter ratio is reached. Nevertheless, there are plenty of examples where severe stem bend and breakage has occurred following delayed thinning or as a result of following more conservative regimes. Irrespective of such examples, thinning leads to an improvement in the height/diameter ratio. It also opens the canopy, allowing more snow to fall directly on the ground rather than be intercepted by the crowns, and causes greater wind turbulence which can help shed snow from crowns except in rime-forming conditions. On the other hand, thinning encourages crown growth which will eventually lead to a return to a high-risk situation. However, partially compensating for this is that radiata pine wood increases in strength with age, there being a marked strength gradient from pitch to outerwood. In general, then, thinning reduces the amount of snow damage. This conclusion is supported by a survey of snow damage in a tending trial (S568) at 560 m a.s.l. in Berwick State Forest. Although the trees were only nine years old with a stand height of 7 — 8 m, those treatments still carrying the initial stocking of around 1700 stems/ha suffered damage to 25 — 55% of the crop, depending on aspect, while those that were thinned to around 600 stems/ha five years before the storm suffered damage to only 12 — 30% of the crop.

MANAGEMENT TO MINIMISE SNOW DAMAGE

Altitudinal Limit for Economic Production Forestry

The substantial area of production forest at the upper altitudinal limit that has not been affected by snow, and the wide altitudinal range of snow-prone sites, suggests that there is little justification for altering the current general altitudinal limits for economic production forestry on the ground of potential snow damage.

Classification of Snow-prone Sites

The identification and classification of snow-prone sites prior to establishing a tree crop should be possible using a combination of known local climatic patterns and physiography. While meteorological data can be helpful in determining local climatic patterns, new areas acquired for afforestation are often remote from established climatological stations. The advice of local farmers, and especially that of the previous owner of the land, can be invaluable. They will know from experience the direction that snow-bearing storms are likely to come from, and the places where snow is likely to accumulate in drifts. Another way of getting this information is to take vertical aerial photographs after a storm and after sufficient time has elapsed for all but the snow-drifts to have melted.

The following classification system for identifying different snow-prone sites is suggested:

Snow Damage Site Class

1. Sheltered lee slopes, close to a ridge, where the deepest snow-drifts are likely to occur.
2. More extensive lee slopes, usually of lesser slope and downhill from the above, where heavy snow is deposited and the wind direction compounds the detrimental effects of asymmetrical crown development.
3. Windward slopes, where the wind direction cancels the effects of asymmetrical crown development.
4. Exposed ridge sites, where wind forces are at their highest but little snow accumulates.
5. Other sites, where snow may fall but is unlikely to cause any damage except in exceptional circumstances.

This classification system could be used as an aid to management planning by clearly identifying where the different classes of snow-prone sites are likely to be, and providing the opportunity to make management decisions that will minimise the losses caused by snow damage. An example of the use of this system is shown in Fig. 4.

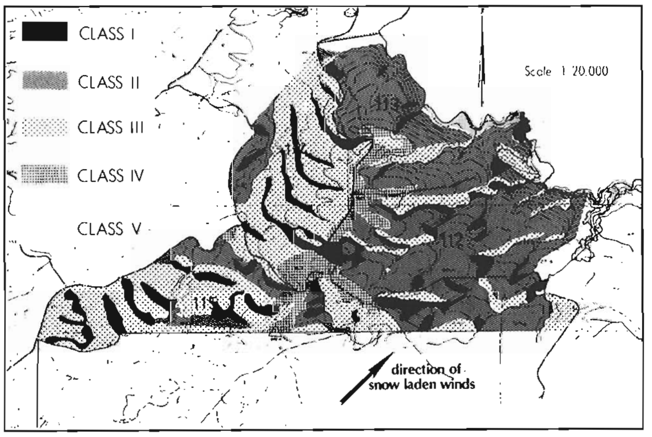

Fig 4. Snow damage site classification — Berwick State Forest. Cpts 112 to 115.

Choice of Species

The rapid growth rate of radiata pine in New Zealand, its ready marketability and conventional economics make it very difficult to justify the planting of alternative species. Radiata pine is likely to remain the principal species in production forestry in New Zealand, even at the higher altitudes where there are risks of snow damage. Nevertheless, there is potential for other species which are better adapted to shedding snow. Stands of different species would need to be large enough to form manageable units, particularly at the harvesting stage.

1. *Douglas fir*
   As an alternative to radiata pine on snow-prone sites, Douglas fir has a lot of merit provided it is not planted on exposed sites (such as site 4 in the classification system) or on sites that are not freely drained.

2. *Eucalypts*
   Eucalypts may be well suited to the fertile, loessal soils often found on lee slopes — snow damage site class 1 — and deserve consideration, though careful attention needs to be paid to their site requirements before planting on a large scale. *E. delegatensis*, *E. fraxinoides* and perhaps *E. fastigata* look promising species with tolerance to frost, snow and exposure. (Wilcox et al, 1985). *E. nitens* and other blue gums are often severely damaged by insects.

3. *Corsican Pine*
   In view of its excellent timber properties and ability to maintain a steady growth rate even in very adverse site and climatic conditions, Corsican pine may be a viable alternative where all else fails and it is essential that the site be afforested. The slow growth rate of this species — about half that of radiata pine on equivalent sites — suggests that it may not be a serious contender for replacing radiata pine on all snow-prone sites.

4. *Other Species*
   It seems possible that some of the very valuable Japanese species, which grow in a similar maritime climate in Japan, may be suitable alternatives, as could western red cedar and Lawson cypress. Trials of these species on the more fertile sites are warranted.

Improved Genetics

The current radiata pine breeding programme provides two options for improving the ability of this species to withstand snow. The first is the alternative for uni- or multinodal branching characteristics. Snow-shedding ability is greatly enhanced if branches are small and short. Uninodal trees tend to produce large diameter branches and often have 'basket' whorls which provide weak points likely to break under load. Seedlings grown for snow-prone areas therefore should come from multinodal parents rather than from uninodal parents.

The second option is wood density. The positive correlation between wood density and strength suggests that trees with higher density should be better able to withstand the forces of snow and wind. Selection for high wood density would be particularly advantageous as density is known to decrease with latitude and altitude (Cowan and McConchie 1982).

Silvicultural Treatment

Douglas fir, with its short, horizontal upper branches and long, deflexed lower branches, and *E. delegatensis*, with its vertically hanging leaf system, are well equipped to shed snow easily. These inherent abilities to shed snow would seem to outweigh most silvicultural considerations. Radiata pine, on the other hand, does not have a morphological habit that is conducive to shedding snow easily. Silvicultural treatment thus has a significant role in reducing snow damage.

CONCLUSIONS

Snowfalls of the type experienced in May 1983 will continue to be a regular feature of the climate in southern New Zealand. This fact should be recognised in forest planning so that forests can be managed to minimise losses from snow damage.

The high-risk sites should be identified before afforestation of new areas commences. Sites where radiata pine is likely to be totally destroyed by snow damage should either be left unplanted, or planted in a more snow-tolerant species such as Douglas fir or *E. delegatensis*. Sites where radiata pine is likely to sustain severe snow damage should be considered either for planting in a more snow-tolerant species, or, if planted in radiata pine, should be planted at wide initial spacing and given heavy early thinnings and prunings. On other sites, radiata pine should perform adequately provided the stands are thinned and pruned as above.

Total control of brush weeds is essential on all snow-prone sites. Efforts should be made to breed radiata pine with a multinodal habit and high wood density.

TABLE 2: THE EFFECT OF SILVICULTURAL TREATMENT ON THE VULNERABILITY OF RADIATA PINE TO SNOW DAMAGE

Silvicultural Treatment	Low Vulnerability	High Vulnerability
Weed Control	Clean, weed-free sites.	Weedy sites, especially heavy infestations of gorse and broom.
Treestocks/planting quality	Well planted, sturdy treestocks with well trimmed root system.	Weak seedlings with long straggly root systems, and poor planting technique.
Initial spacing	Wide initial spacing (1000 stems/ha or less).	Close initial spacing (1600 stems/ha or more).
Planting configuration	Planting lines running up/down slope.	Contour planting N.B. This may be counteracted with wider spacing between the trees.
Thinning	Maintain a relatively low stocking from an early age — e.g. thin from 1000 to 500 stems/ha at 6 m mean top height (MTH) and from 500 to 250 stems/ha at 10 m MTH.	High stockings and delayed thinnings.
Selection of crop trees	Favour multinodal individuals with symmetrical crowns and fine branches.	Favour uninodal individuals with asymmetrical crowns and coarse branches, acute angle branches or forks.
Pruning	Keep crown small by pruning early — e.g to 2 m at 6 m MTH 4 m to 8 m MTH 6 m at 10 m MTH and apply Neil Barr technique (1)	Maintain a large crown by pruning late and thinning heavily.

(1) The Neil Barr technique involves the selective removal of large branches and the shortening of branches in the crown above each standard pruning lift.

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