THINNING AND SALVAGE STRATEGIES IN PLANTATIONS PRONE TO STORM DAMAGE — CASE STUDY OF RADIATA PINE PLANTATIONS IN THE OVENS VALLEY, VICTORIA

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ABSTRACT

Storm damage is becoming recognised as a significant problem in the Ovens Zone as the plantation area expands, because stands with about 1600 stems/ha on high-quality sites (>SI 27) become increasingly prone to "collapse" once the stand height exceeds 20 m. Commercial thinning before the stands become unstable is not feasible because yields are quite low (60–75 m^3/ha) and piece size is small (0.05–0.08 m^3). Harvesting systems for such areas need to be specially designed to operate economically at these levels. Systems are also needed to handle smashed and tangled material until new silviculture aimed at providing more stable stands becomes effective.

In the long run an approach to control appears to lie in the promotion of low "slenderness ratios", i.e., the ratio of stand height to mean diameter (in damaged stands typically in excess of 100). Lower slenderness ratios and hence more stable stands are achievable by wide initial espacements and by early non-commercial thinning. There appears, however, to be no silvicultural means to regain stability in the dense unthinned stands which are already in excess of 20 m stand height.

INTRODUCTION

The problems that exist in the radiata pine (*Pinus radiata* D. Don) plantations of the Ovens Valley are by no means unique. Stand instability in conifer plantations is a problem in many other places, especially places with oceanic climates such as New Zealand and the United Kingdom. There is not much written, however, about the management of unstable stands – perhaps because the managers are too busy drawing up salvage plans.

The problem for any forest manager in this situation is that, despite imperfect knowledge, decisions have to be made on the treatments and harvesting methods appropriate in unstable areas or where damage has already occurred. In making these decisions he will be greatly constrained by market conditions, future supply commitments, and the available harvesting systems.

Review of Literature

The literature on stand instability and storm damage is considerable but it frequently consists of more or less narrative accounts of the damage caused by particular catastrophic storms. There are in fact at least 167 reports available from 25 countries since 1833, according to a bibliography obtained at the Commonwealth Forestry Institute, Oxford. These papers usually describe the extent of damage in relation to species, site condition, topography, location, and state of the stand. Taken together they demonstrate the magnitude of the problem, but definite conclusions on predisposing factors are hard to find for the evidence is frequently sketchy or contradictory. The only common predisposing factor is that of soil condition – soils which are liable to waterlogging or which are shallow prevent root penetration and are liable to windthrow (Irvine 1970; O'Cinneide 1974; Foot 1975; Pyatt 1968; Chandler 1968; Cremer *et al.* 1977).

In upland United Kingdom, where wind damage is undoubtedly the major management problem, the soil is typically a heavy peat or gley which is subject to periodic waterlogging.

On the Canterbury Plains and in the Nelson district in New Zealand regular devastation of radiata pine plantations is recorded (Wendelken 1955; Papesch 1971; Wilson 1976). Soils on the Canterbury Plains are compacted gravels and the comment has been made that it is just as well this is so, as damage is said to be inevitable in the extreme winds that occur there and the subsequent salvage is much easier with uprooted rather than smashed trees (Thomson 1976).

In the Ovens Zone plantations stems are bent and broken rather than uprooted and this creates a particular problem. In seeking guidance from the literature it soon becomes apparent that little basic study of wind movements in and over plantations and of resultant tree reactions has been done. Those reports that do exist are complex aerodynamic analyses which have little to offer the practitioner (Oliver & Mayhead 1974; Papesch 1974; Mayhead 1973). They do show, however, that the more turbulent the airflow the greater is the energy transfer from the moving air stream to the stand and the greater is the likelihood of damage. It follows that stand conditions which produce an uneven canopy surface, such as that after outrow thinning, could increase the hazard because of their tendency to increase turbulence. Similarly, leading edges of stands which directly block the wind may create turbulence which causes damage within the plantation (Somerville 1980).

There are some reports dealing with field techniques which are of value, although most tend to concentrate on methods of site preparation and planting which can increase rooting depth (Booth 1974; Godwin 1968). One report which does deal with stand characteristics is that of Brunig (1973) who discussed stability in terms of the slenderness value, i.e., the ratio of height to diameter (h/d). Stable open-grown trees taper rapidly and thus have slenderness values which are typically between 20 and 40. The greater the slenderness value the more the stem is swayed by the wind and the sooner it is thrown or broken. The importance of minimising turbulence is also pointed out and the comment made that stands which do not have an appropriate slenderness value are particularly endangered when the surface roughness is increased by a thinning. For radiata pine Brunig proposed that the slenderness value of individual stems should be kept between 60 and 70 after the stand height reaches 10 m. This value is said to be likely to maintain stability yet avoid utilisation problems through excessive taper.

This is where the traditional silviculturalist and the harvesting technologist diverge, of course, for it implies that if extraction thinnings are to be done they should be light, regular, and selective, or in other words, involve high costs and low yields. In wind-prone areas, therefore, regimes which involve either no thinning at all or early non-commercial thinning are attractive. The New Zealand direct sawlog regime (Fenton & Sutton 1968) should have particular value since, as Brunig pointed out, green pruning should also promote stability by reducing crown weight and by allowing wind to penetrate the stand. The penetration of wind reduces the turbulence which is generated by the blocking of the airstream. Further, it was shown some time ago by Jacobs (1936, 1954) that trees which are free to sway in the wind develop larger diameters for a given height (i.e., lower slenderness ratios) than those which are prevented from doing so.

The argument for early non-commercial thinning in wind-prone areas has been developed independently and carried considerably further by Moore (1976) who claimed that it is impossible to thin conifer crops commercially in windy oceanic climates on wet soils such as occur widely in the United Kingdom. This is because a stand is said to become unstable long before it comes financially rewarding (Moore 1976). A system called "Oceanic Forestry" was therefore proposed with heavy non-commercial thinnings to promote wind-firmness. The thinned stems were to be cut above the first green whorl so that the lower tree remained alive to suppress scrub and branch growth on the lower bole of the crop trees. The species used was Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and the method may well work although virtually no data are provided.

In summary, there is advice available on what we might have done in the past or on what we should do next time, but not much to help at present. The abundant literature does serve, however, to make the point that stand stability has long been a major concern in forest management.

STUDY AREA

Climate

The Ovens Valley Plantation Zone in north-eastern Victoria (Fig. 1) lies between latitudes 36° and 37° south and the weather pattern is influenced by sub-polar maritime air in the winter and continental subtropical air in the summer. During winter, frontal activity associated with a succession of low-pressure systems dominates the weather and brings most of the precipitation, including occasional snowfalls. In the summer, subtropical high-pressure systems bring warm dry weather characterised by sudden and intense thunderstorms. Annual rainfall varies (with elevation and location) from about 950 to 1200 mm. Precipitation is reasonably well distributed throughout the year although summer rains are rendered less effective by their high intensity and short duration. The prevailing winds throughout the year are westerlies, coming from either the south-west or the north-west, but southerlies and northerlies increase from September to February. Maximum wind gusts expected in the region over a 50-year return period are 40–44 m/sec (148–157 km/hr) (Whittingham 1964). Mountainous terrain forms an obstacle to the moist westerly winds, thus intensifying thunderstorm activity and turbulence in the region.

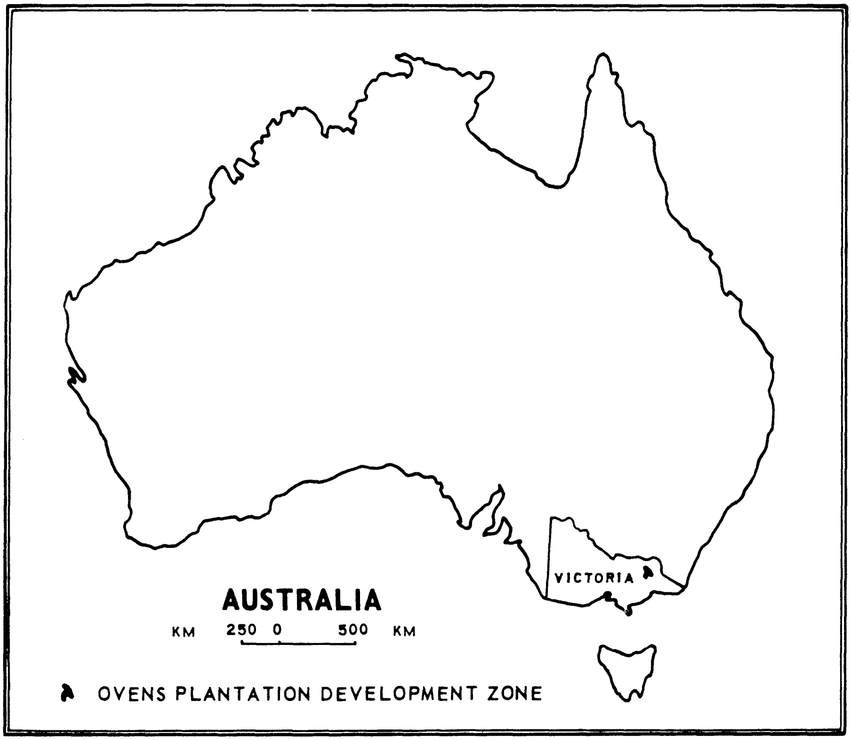

FIG. 1—Location of the Ovens Valley Plantation Zone.

The Plantations

The plantations of the Ovens Zone comprise 18 500 ha of State-owned radiata pine located on the foothills of the Australian Alps over an elevation range of 200–870 m. Soils are mainly duplex and derived from Ordovician sandstones and shales. They are of adequate fertility and well structured, allowing good root penetration. Deep alluvial soils of high fertility occur along river flats and terraces and there are some areas of brown gradational clay soils developed on Devonian granite.

Ground slopes are frequently steep and about 40% of the older plantations are located on slopes greater than 20°. The younger age-classes (<10 years) are generally on flatter terrain as a 20° average slope limit was introduced for new plantations in 1970. Initial establishment at fairly high stocking rates (1680 stems/ha) has been used throughout until about 1978. Areas where thinning will be difficult or which are especially prone to wind damage are now established at 1000–1100 stems/ha.

The age distribution at present is shown in Table 1 and it can be seen that there is a large area of young stands of about first-thinning age (10–15 yr). There is also a large area of stands in the 16–20 years age-class and these are predominantly unthinned because until recently there has been no substantial smallwood market. These are the problem stands, especially those on high-quality sites. They are becoming unstable even without thinning, yet they will be of the greatest importance for the maintenance of adequately sized sawlog and veneer log supplies after the limited areas of older stands are harvested.

TABLE 1—Radiata pine age-class distribution in the Ovens Zone plantations in 1981

Age-class (years)	Area (ha)
1–10	7672
11–15	3558 (50% site index >27)
16–20	2594 (60% site index >27)
21–30	448
31–40	995
>40	1792

NATURE OF THE WIND DAMAGE

It is well known from past experience that radiata pine is liable to severe wind damage if the stand density is reduced significantly once the individual stems have become tall and slender. The height at which a stand becomes vulnerable varies with site quality and stocking and its significance is illustrated by its inclusion as an overriding consideration in Lewis' optimum thinning guide for radiata pine in South Australia (Lewis *et al.* 1976). This susceptibility to wind damage is not usually an insurmountable problem because thinning can be dispensed with. Yields are simply delayed and eventual sawlog sizes reduced. Unfortunately in the Ovens Valley the problem is more serious because stands on the very fertile sites tend to collapse in fairly normal winds when they reach top heights much in excess of 20 m, regardless of whether they are thinned or not. The trees develop bends and lean into their neighbours so that gaps are created in the stand by a progressive collapse. Some trees may be unrooted and some may snap but in the main they just lean in a tangled mass from which they are incapable of recovering. Stands in which this condition is incipient are liable to severe damage from wind or snow storms. Wind storms, often accompanied by rain and sometimes by snow, occur commonly in the area and in recent years, with the increase in area of susceptible stands, there has been a considerable amount of damage.

The stability problem has been evident for some years and several attempts have been made to obtain definitive information on the nature of susceptible stands, but such is the capricious nature of the wind storms that little conclusive evidence has so far been obtainable. There has been a considerable body of local knowledge accumulated and some general statements can be made:

(1) The risk of damage is considerably higher on areas of high site index* (i.e., greater than about 27) than on lower quality areas. (This observation is not explainable on the basis of h/d ratios and may be influenced by variations in the mechanical properties of the wood on the different sites.)

(2) In these stands the risk increases progressively once top height exceeds about 20 m.

(3) The risk increases progressively as the slenderness ratio (the ratio of stand height to mean diameter) increases and is high once the ratio exceeds about 120, particularly on high-quality sites.

The damage caused by a series of wind storms in December 1980 provides a considerable amount of evidence to support the hypotheses set out above. All stands affected were in excess of 20 m stand height and of high site index (>28) (Table 2). The slenderness ratio is, in every damaged stand, in excess of 110. The value of this ratio as a criterion for stability has not yet been determined fully but the figure for damaged stands is certainly above the 60–70 recommended by Brunig (1973).

The stands were also mapped into damage-severity classes as shown in Table 2. No obvious relationship between the degree of damage and the stand parameters is apparent, however.

OPTIONS FOR TREATMENT

Consideration needs to be given to two categories of stands – the areas which are susceptible to damage and those which are already damaged. For both categories there are basically three options – to do nothing, to thin, or to clearfell. The major constraint used in establishing the criteria by which to choose between these is that it is highly desirable to carry through as many stands as possible to a rotation which will produce mainly sawlogs. This arises because with a finite total market the production of excessive amounts of pulpwood from salvage or premature clearfelling would have the effect of reducing the amount of normal thinning that can be done. The second reason is that the present annual sawlog commitments are such that the rotation length will inevitably be reduced to about 30 years for a period at the end of this decade. Premature clearfelling means that the sawlogs which will be greatly needed at that time would be harvested now as pulpwood.

The choice of management option depends basically on the extent of the damage and the likely composition and stability of the residual stand. Some attempt has been made to quantify these factors as an aid to decision making and the procedure is set out as follows.

Susceptible but Undamaged Stands

Thinning is not carried out in stands which are very likely to be unstable but which are as yet undamaged. The criterion for this decision is a stand height of 23 m in practice rather than the 20 m which is thought to be necessary for security. This limit is set at a level which carries some risk of damage after thinning but is accepted

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* Site index = stand height at 20 years. Stand height is taken as the mean height of the 50 tallest stems of the 75 largest diameters per hectare.

TABLE 2—Stand parameters for unthinned sections damaged by wind storms in December 1980

Damage photoclass*	Cpt	Age (yrs)	Average elevation (m)	Pre-damage compartment average					
				Site index	Stocking (stems/ha)	Basal area (m^2/ha)	Mean† diam. (m(d))	Stand height (m(h))	Slenderness ratio (h/d)
Severe	210.02	14	335	33.4	1547	36.4	0.17	25.8	149
	214.01	16	345	28.2	1294	42.0	0.20	24.7	121
Moderate	218.01	11	335	33.7	1740	39.5	0.17	20.4	119
	219.01	11	350	34.0	1586	40.3	0.18	20.6	114
	202.01	13	330	29.8	1606	41.3	0.18	21.5	118
	208.01	15	290	31.5	1425	40.6	0.19	25.9	136
	210.01	15	350	30.2	1253	40.1	0.20	24.9	123
	210.02	14	365	33.4	1697	49.6	0.19	25.8	133
	211.01	15	410	30.4	1683	38.0	0.17	25.1	148
	214.01	16	405	28.2	1432	45.8	0.18	24.7	138
	215.01	16	395	28.7	1517	46.9	0.20	25.1	126
Light	208.01	15	310	31.5	1571	42.3	0.19	25.9	140

* Subjective estimates from aerial photographs

† Quadratic mean diameter

because of the pressing need to carry out thinnings in order to secure future sawlog supplies. It also acknowledges the problem that thinning at stand heights less than 20 m produces relatively low yields of high-cost wood. Outrow thinning to a degree of 1 in 5 is accepted for the same reason.

The selection of acceptable stand height is fairly subjective but is based on the slenderness ratio. For fully stocked stands in the Ovens region the ratio typically begins to exceed a value of about 120 at about 23 m on high-quality sites (site index >27) and at about 20 m on lower quality sites. The higher slenderness ratios at lower stand heights on the lower quality sites is an apparent anomaly. It arises because survival rates at establishment (and hence stockings) are typically higher on low quality sites than on the better sites. This is probably because of reduced competition from scrub species. The development of the slenderness ratio with stand height for stockings typical of various sites is illustrated in Table 3.

Damaged Stands

Extent of damage

For operational reasons the damage area needs to exceed 2 ha before clearfelling would be considered.

Stand stocking after salvage

A stand is considered to need at least 225 stems/ha available for retention after salvage thinning if it is to be worth maintaining (*c* 20-year-old stands).

Note: Simulation studies using SRSS indicate that there is a considerable loss of total volume production if the retained stocking is less than 250 stems/ha but a slightly lower level is accepted in order to minimise the clearfelling. SRSS is the simulation system used generally for growth prediction in Victorian State plantations and is a development of the previous program FORSIM (Tregonning & Aeberli 1979).

Stand stability after salvage

There is no point in salvage thinning if it is followed by collapse of the residual stand, and in certain situations this is quite likely. The simulation system was also used in an attempt to estimate the degree of certainty that should be required if a choice of thinning rather than clearfelling is to be made. These studies suggested that a probability of at least 0.6 that the residual stand will remain stable is necessary if the volume expected at rotation age is to be greater than that obtainable over the same period from salvage clearing and replanting. This calculation is, however, approximate and is included in the paper as a demonstration of a methodology rather than as a definitive statement. The calculation is illustrated for a typical stand in Appendix 1.

The estimation of this probability in the field is the next problem. As yet it is a matter of rather subjective silvicultural judgment and perhaps it will remain so. The possibility does seem to exist that by further study of the development of the slenderness ratio some quantification will be possible. However, the silviculturist clearly needs to be fairly certain that the residual stand will remain stable in order to salvage by thinning rather than by clearfelling.

TABLE 3—Expected volume yield and average piece size from first thinning in typical stands in the Ovens Zone plantations

Risk of instability	Stand height (m)	Site Index 25			Site Index 30		
		Slenderness ratio	Vol. (m^3/ha) >10 cm s.e.d.	Av. piece (m^3)	Slenderness ratio	Vol. (m^3/ha) >10 cm s.e.d.	Av. piece (m^3)
Low	17	113	60	0.05	106	62	0.06
	20	112	74	0.07	116	77	0.08
High	23	130	92	0.08	126	93	0.10
Very high	25	136	105	0.09	132	105	0.11

Note: Based on simulation studies for typical stands using SRSS of fifth row outrow thinning with selection in bays to 500 stems/ha

Thinning Yields in Relation to Stand Stability

As has been described, the risk of wind damage after thinning becomes progressively greater as stand height increases beyond 20 m. The problem is that yields and piece size are low if thinnings are carried out sufficiently early to ensure stability. Table 3, which is again based on simulation studies of typical stands, shows that at stand heights of 17–20 m the available yields are likely to be only about 60–75 m^3/ha with an average piece size of 0.05–0.08 m^3.

The expected yields increase with stand height, as does the risk of wind damage. Yields of 100 m^3/ha do not become available until stand height reaches about 25 m. By this stage h/d ratios have become high in the present stands and the risk of wind damage is high especially after thinning.

IMPLICATIONS

There are two important implications, or perhaps they should be called alternatives, for the design of harvesting systems suitable for plantations which are liable to instability. The first is that they must be able to handle severely bent and tangled stems and broken pieces of random length. The salvage thinning is a particular problem because damage to the limited number of residual stems is quite likely to occur during the salvage operation. The second implication is that, since on-schedule first thinning operations should be completed before the stand height reaches 20 m, yields will be restricted to a maximum of about 75 m^3/ha with an average piece size of 0.05–0.08 m^3. The problem for the harvesting technologist then is to design systems which can provide wood at acceptable cost at this level. Past experience suggests that it won't be easy.

Silvicultural regimes for areas prone to wind damage should aim to produce stands in which low slenderness ratios can be maintained with a minimum amount of thinning. Wider initial espacement (1000–1100 stems/ha) has been introduced as a means of achieving this and the problem may eventually become less significant. There appears little that can be done silviculturally in stands that are already unstable.

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APPENDIX 1

DATA FOR A TYPICAL UNTHINNED RADIATA PINE STAND, DAMAGED OR PREDISPOSED TO DAMAGE, IN OVENS ZONE PLANTATIONS

The expected volumes at the varying probability levels for damage are calculated on the basis of an assumption that the proportion of the thinned stands actually damaged will be equal to the probability of damage occurring. For example, if the probability of damage is 0.1 then 10% of the susceptible stands will be severely damaged and require salvage clearfelling and replanting. The remainder will continue to rotation age.

Stand parameters: Age 16 yrs; Stand Ht. 24.8 m; Basal area 40 m^2/ha; Slenderness ratio 132; Site Index 30; Stocking 1450 stems/ha.

Table showing volume production expected at rotation age at various probability levels of stand stability after salvage thinning, compared to volume from salvage clearfelling and replanting in the same period.

Treatment options for a damaged 16-year-old stand	Volume production expected (m^3/ha) at normal rotation age (35 years)
Option 1 — Salvage clearfell and replant immediately	594 (Vcf)
Option 2 — Salvage thin and then clearfell only if further damage occurs	
Probability of stand remaining stable (Pz)	
0.5	562 V(Pz)
0.6	598
0.7	634
0.8	671
0.9	707
1.0	744

Notes: (i) Vcf = S + R

S = Volume from salvage clearfelling at age 16

R = Volume available from replacement stand at age 19 (i.e., equivalent to the time of clearfelling if the stand had been thinned rather than clearfelled after damage.

(ii) V(Pz) = A + B (Pz) + C (1–Pz)

A = Volume from salvage thinning at age 16

B = Volume from residual stand at rotation age

C = Volume from clearfelling after collapse of residual stand (assumed to occur 5 years after salvage).

(iii) Volume estimates were obtained by using the Softwood Resources Scheduling System (SRSS).