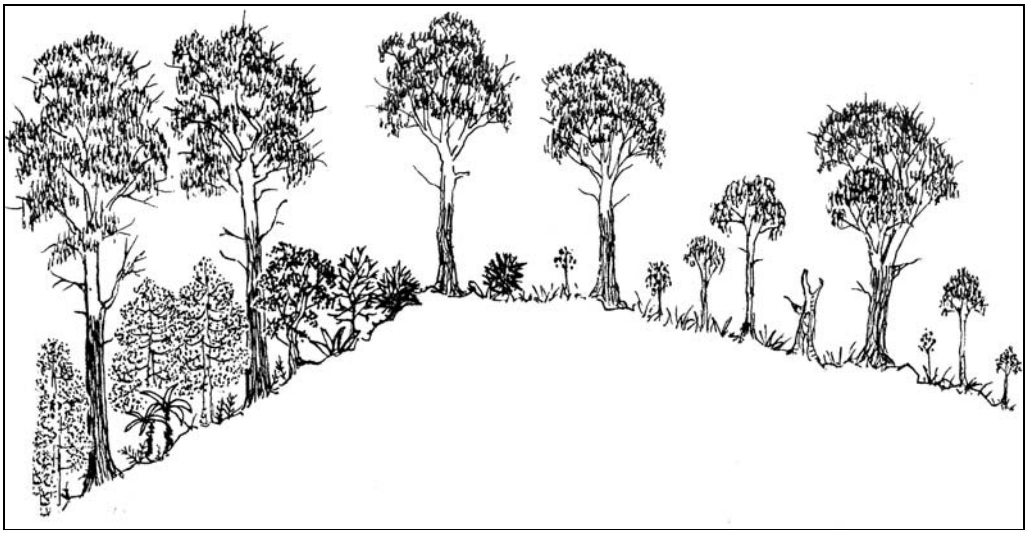
Native Forest Silviculture

TECHNICAL BULLETIN No. 2

2010



Eucalyptus delegatensis Forests

Forestry Tasmania
79 Melville Street
HOBART 7000

ISSN 1034-3261

February, 2010

Acknowledgments
Line drawings are derived from original works by Fred Duncan.

This bulletin should be cited as:

Forestry Tasmania (2010). *Eucalyptus delegatensis* Forests, Native Forest Silviculture Technical Bulletin No. 2, Forestry Tasmania, Hobart.

Prepared by Mark Neyland
First edition (1990): Prepared by Michael Battaglia
Layout and design by Leigh Edwards
Division of Forest Research and Development,
Forestry Tasmania.

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Contents

Part A: Silvicultural Prescriptions for the Management of *E. delegatensis* Forests

1. Introduction

Eucalyptus delegatensis subsp. *tasmaniensis* typically occurs from about 400 m asl to about 900 m although it is also found less commonly at both higher and lower altitudes. More than half of the *E. delegatensis* forests in Tasmania occur in the Central Highlands region, with significant areas also in the north-east and eastern highlands. Of the total area of *E. delegatensis* forest, 40% is on State forest or other Crown Land available for wood production, 25% is privately owned and 35% is reserved. The area of *E. delegatensis* forest by tenure and region is shown in Table 1.

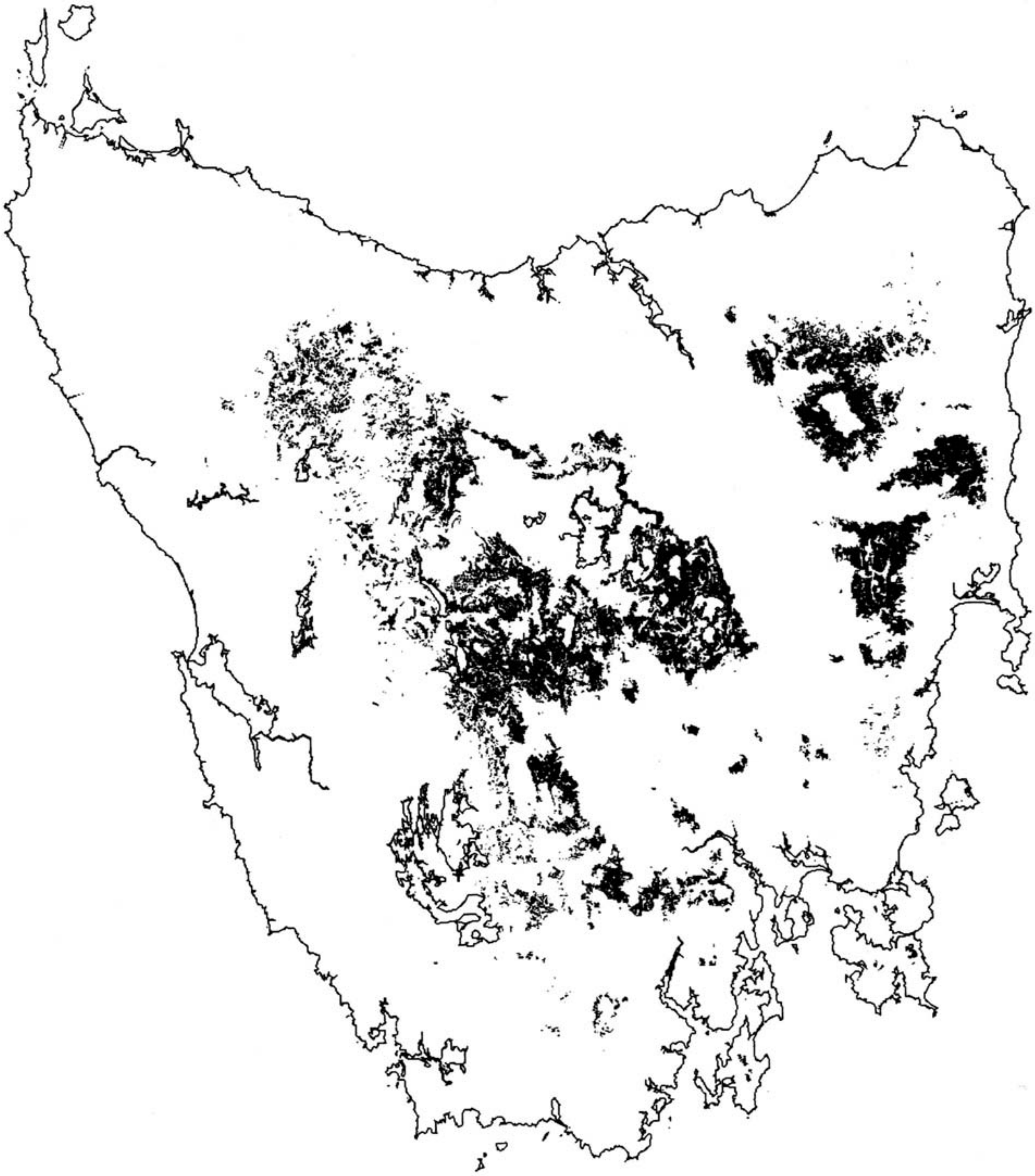
Table 1. Area of *E. delegatensis* forest by tenure and RFA vegetation community (after Tasmanian and Australian Governments 2007).

RFA Code	*RFA Community*	*Total reserved*[1]	*State forest and other public land*[2]	*Private land*[3]	*Total*
D	Dry *E. delegatensis* forest	98 000	91 000	98 000	287 000
DT	Tall *E. delegatensis* forest	97 000	134 000	42 000	272 000
	Totals	195 000	225 000	139 000	559 000

[1]. Total reserved area includes both formal and informal reserves.
[2]. Excludes all reserves.
[3]. Includes CAR reserves on private land.

Tasmania's *E. delegatensis* forests have had a long history of forest management and have proven amenable to a wide range of silvicultural treatments, including clearfelling, partial harvesting and single tree selection. A long history of selective cutting of these forests and periodic fires lit to promote forage has often resulted in abundant regeneration. The development of an export eucalypt pulpwood market in the 1970s resulted in clearfelling becoming the normal practice. By the late 1970s it had become apparent that regeneration was not always successfully established using the clearfelling technique. A considerable research effort has led to better understanding the silvicultural characteristics and management of these forests. A recognition of the problems of regeneration at high altitudes and the benefits of utilising advance growth has resulted in current harvesting in high altitude forests being predominantly by partial harvesting regimes.

Figure 1. Distribution of *Eucalyptus delegatensis* in Tasmania (after PLUC 1996).



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2. Silvicultural Considerations

The nature of the understorey and the topography of the site are key determinants of the appropriate silvicultural system. For example, on flat sites above 600 m, clearfelling is not recommended as regeneration is prone to frost damage. Clearfelling must be used where the understorey is rainforest or wet sclerophyll shrubs. On flat, frost-prone sites above 600 m with a rainforest or wet sclerophyll understorey, successful regeneration cannot be assured, so **not** logging may be the best option. On such sites, and on any sites above 1000 m, regardless of understorey type, specialist advice should be sought before harvesting commences.

The optimum silvicultural prescription for any stand of *E. delegatensis* forest will be dependent on the stand structure and site conditions. The following guidelines will assist in determining the most appropriate silvicultural prescription for any given site:

1. Keep existing regeneration wherever possible as this has the advantage of being established and is unlikely to die following release from competition.

2. Retain a forested environment during harvesting to minimise the rate of grass invasion, reduce climatic extremes and minimise browsing (i.e. retain 9 - 14 m^2/ha basal area of mature trees wherever there is neither advance growth or potential sawlogs (pole sized regrowth) present).

3. Provide a seedbed that is receptive for as long as possible to allow recruitment in later seasons if the initial germination fails.

4. Provide a seed source for as long as the seedbed remains receptive.

5. Minimise competition so that regeneration can grow quickly to a size where it can withstand climatic extremes (i.e. retain no more than the prescribed basal area of mature trees and remove shelterwoods as soon as practicable once regeneration is established (>1.5 m high)).

6. The combined effects of summer drought and winter cold result in a very short growing season. Consequently it is important that existing growing stock is not wasted.

7. During the regeneration phase, monitoring of browsing animals, and control where required, is essential to ensure successful regeneration.

Figure 2. Selection of the appropriate silvicultural system for *E. delegatensis* forests.

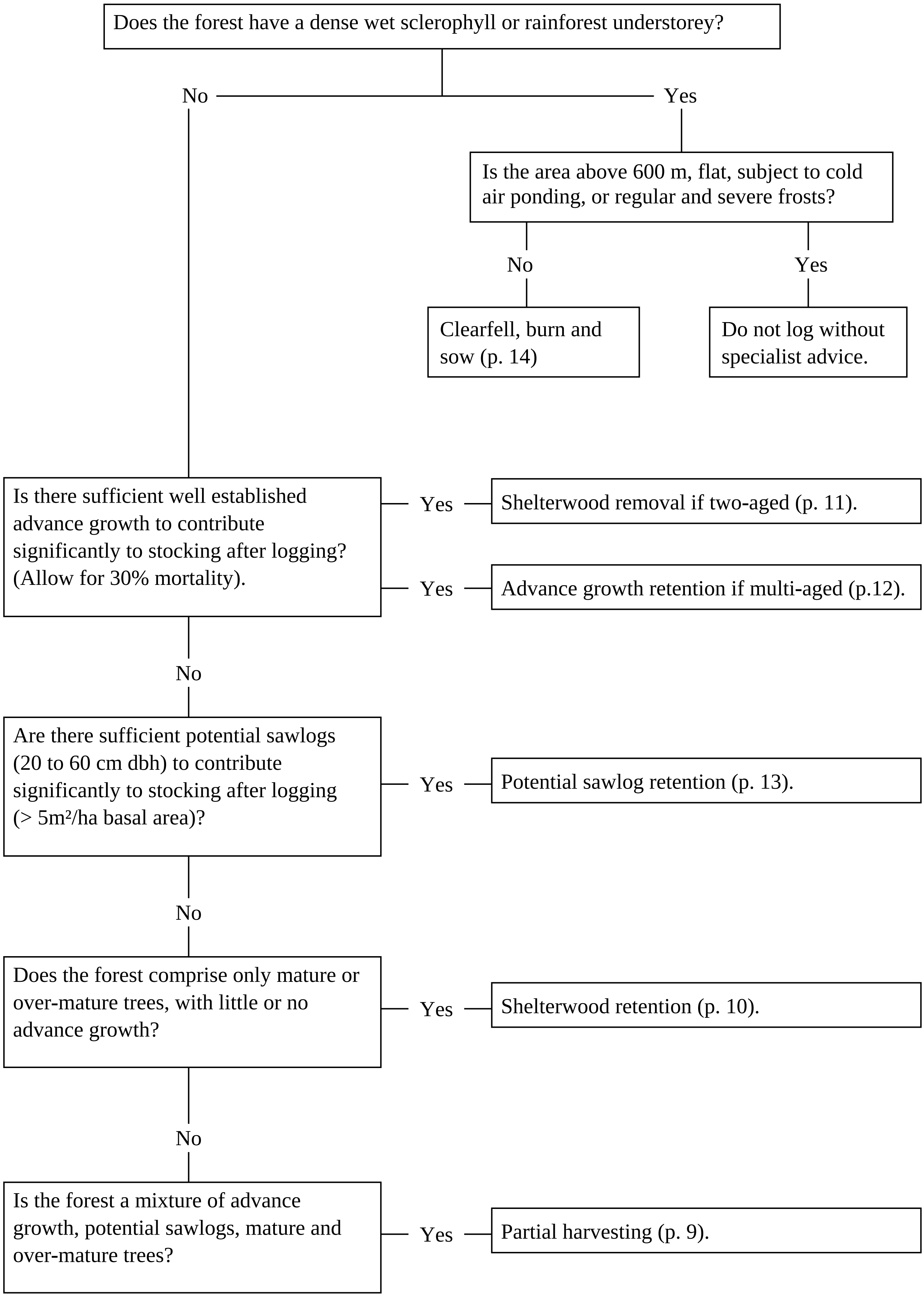


Figure 3. Selection of the regeneration treatment.

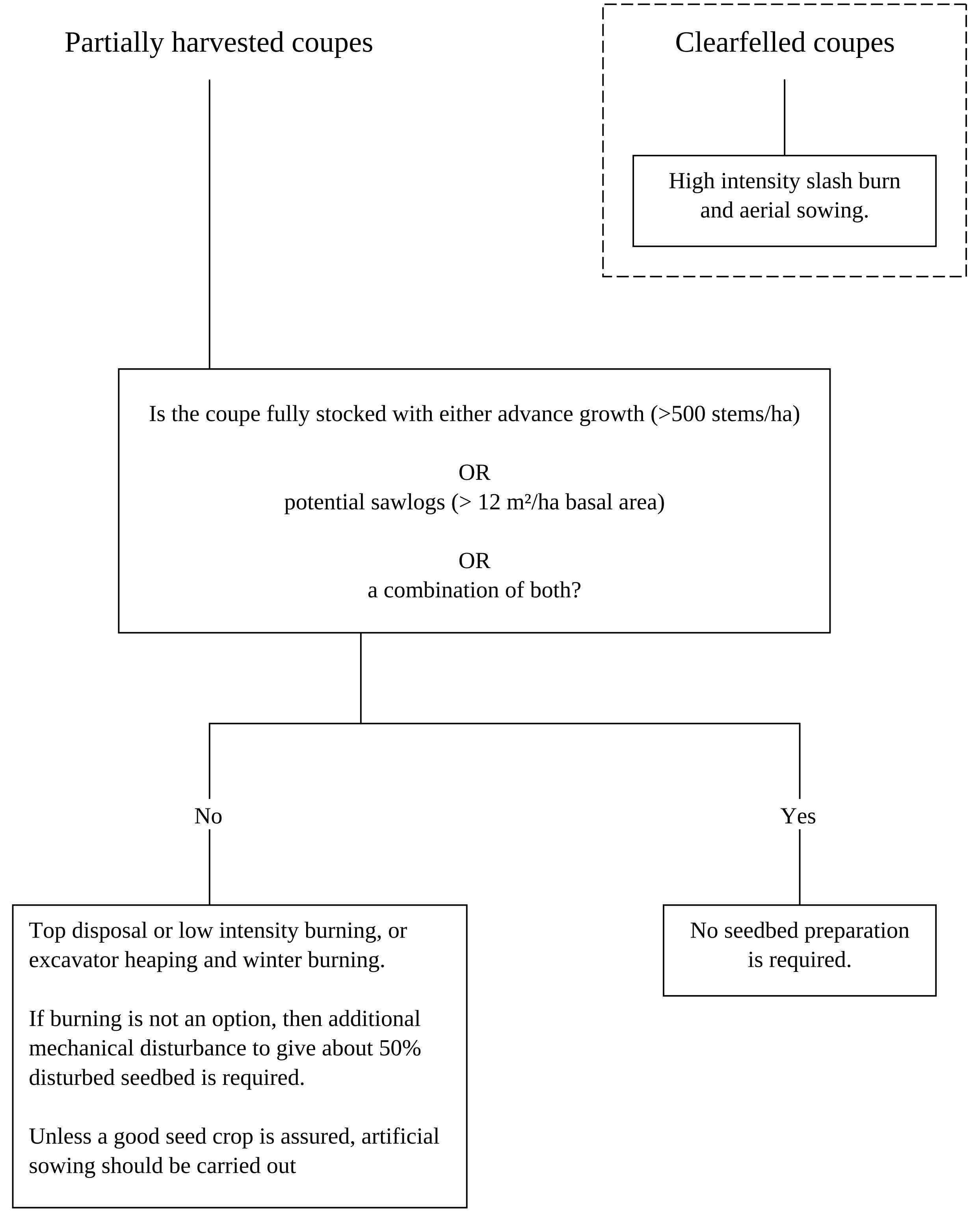
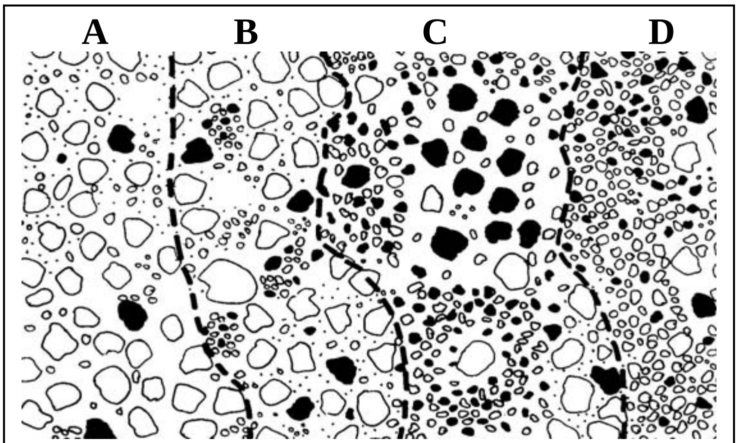


Figure 4. Stand structure and selection of the silvicultural system.

Legend

Trees *Potential sawlogs* *Advance growth* *Seedlings*

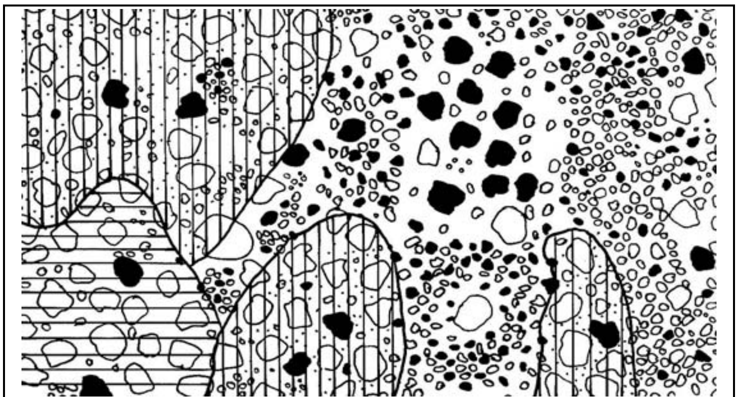
A : Virgin forests have a variety of structures but a preponderance of large sizes is common
B : Small clumps (arising from past single tree harvesting or low intensity fire)
C : Patchy (arising from past intensive harvesting or fire)
D : Even-aged (arising from past clearfelling or severe fire)



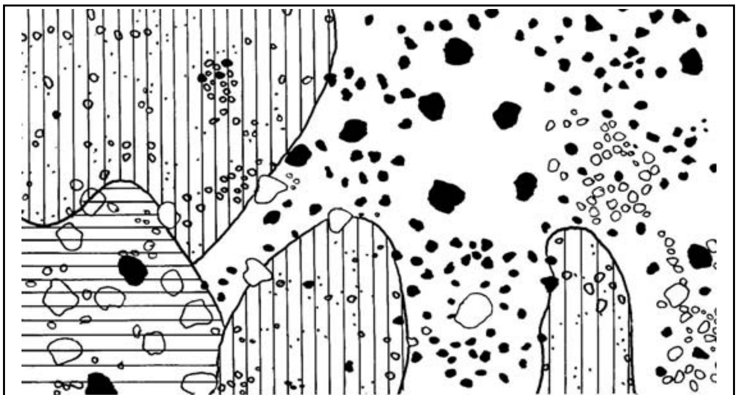
Planning

Lowland dry eucalypt forests may have a variety of structures and tend to be a mosaic of age classes.

The identification of potential sawlogs and advance growth is the first step in selecting the most appropriate silvicultural treatment.

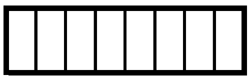


Pre-harvest

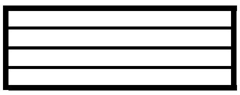


Post-harvest

Patches which contain sufficient potential sawlogs may be spaced. Other vigorous stems should be released by removing poorer quality trees.



Patches which contain an adequate stocking of advance growth should have all marketable stems removed to release the advance growth. Cull trees should be removed.



Patches which contain few or no potential sawlogs or advance growth should have healthy vigorous mature trees retained to provide seed and shelter.

3. Silvicultural Systems and Harvesting Criteria – Partial Harvesting

Eucalyptus delegatensis forests are often comprised of cohorts of trees in a range of size classes – advance growth, potential sawlogs, mature and over-mature trees which occur in a complex mosaic across the coupe. For coupes in such forests, prescription of a single silvicultural system, for example, advance growth retention, will not adequately describe the operation nor provide sufficient information to ensure the best outcomes. In these cases, a blend of the silvicultural systems described below must be used. So, for example, where a patch is comprised of mature trees with little advance growth present, a shelterwood must be applied. Clumps of advance growth, on the other hand, are retained and any overwood should be removed. This approach is illustrated and explained further in Figure 4.

The principles below apply to the nett harvestable area and assume that all special values such as habitat clumps have been managed appropriately in the preparation of the forest practices plan.

The key principles of partial harvesting which must be considered in determining the appropriate prescription for any given coupe include:

- Regeneration must be established before all the overstorey is removed.
- Most advance growth should be retained. Unavoidable damage is to be expected where overstoreys are removed but damage should be minimised.
- Potential sawlogs should be retained at an even spacing. The table on page 13 shows the appropriate spacing for potential sawlogs of different sizes.
- A seed crop assessment should be undertaken and a satisfactory seed crop recorded (as prescribed in Technical Bulletin 1) before shelterwood retention harvesting commences.
- All mature and over-mature trees should be removed except where required as shelterwood. Removal of trees >100 cm dbh is a priority.
- Shelterwood trees should be of good form and quality.
- All cull trees should be removed from harvested areas.

3.1 Shelterwood retention

Appropriate forest stands: *E. delegatensis* forests with open understoreys that lack sufficient advance growth greater than 1.5 m in height. An adequate seedcrop should be present in the retained trees. If the seedcrop is inadequate it is acceptable to sow; however it is preferable when possible to reschedule harvesting until an adequate seedcrop is available.

Harvesting method: All trees are harvested other than those required to provide the shelterwood. Retained trees should have good crowns and be evenly distributed at a rate corresponding to 9–12 m^2/ha basal area on coupes where the rainfall is below 1000 mm. On coupes with higher rainfall, or above 900 m asl, the retained basal area should be 12 to 14 m^2/ha. The proportion of species present on the site prior to harvesting should be reflected in the retained trees.

Regeneration treatment:

Site preparation: Receptive seedbed must be created by low intensity broadcast burning, top disposal burning, excavator heaping, harvesting disturbance or additional mechanical disturbance. On grassy sites, deliberate additional mechanical disturbance may be required to create sufficient seedbed.

Source of regeneration: From seed shed during and after harvesting and from the release of advance growth (where present). If the seed supply is inadequate the coupe must be sown. If rapid grass invasion of the coupe is expected supplementary sowing onto receptive seedbed should be undertaken.

Monitoring and protection: Indicator plots must be established to monitor germination and problems due to inadequate seedfall, lack of receptive seedbed or browsing damage. As the plots are a measure of the success of the seedfall on the coupe, they should not be artificially sown. An additional sown indicator plot would be advantageous to better understand germination and growth rates in the absence of browsing.

Browsing damage: Browsing transects should be established and monitored, and control of browsing undertaken if required, as prescribed in Technical Bulletin 12.

Regeneration survey: A seedling regeneration survey must be carried out about two years after the regeneration treatment, unless the coupe has passed progressive harvesting assessment. A multi-aged survey is the appropriate method where shelterwood retention occurs as a mosaic within patches treated by the advance growth or potential sawlog retention methods.

3.2 Shelterwood removal

Appropriate forest stands: Two-aged forests comprising the mature stems retained in a previous shelterwood retention harvest and now stocked with advance growth.

Harvesting method: The retained shelterwood should be removed in a second harvest, when the coupe is stocked with vigorous regeneration >1.5 m in height.

The shelterwood should be removed as soon as possible after the regeneration is established, and before the retained trees suppress the regeneration, generally between 5 to 15 years after harvesting.

Regeneration treatment: Shelterwood removal is only undertaken when the stand is stocked with advance growth. No additional regeneration should be required. However, minimisation of damage to the advance growth is essential to leave the stand in a healthy and well-stocked condition following harvesting.

Regeneration survey: Either a sapling regeneration survey must be completed prior to the shelterwood removal harvest, or a seedling survey completed after the harvest, unless the coupe has passed progressive harvesting assessment.

3.3 Advance growth retention

Appropriate forest types: Uneven-aged forests containing advance growth that has good potential for further growth. The cohorts of advance growth are often of different ages as they arise from different disturbances.

Harvesting method: Most mature and over-mature stems should be harvested. Regardless of the understorey type (grassy, sedgey, heathy or shrubby), the advance growth should be clearly taller than the competing understorey before the overstorey trees are removed.

Regeneration treatment: Advance growth retention is only undertaken when the stand is stocked with advance growth. No additional regeneration should be required.

Regeneration survey: A multi-aged survey must be carried out within one year of the regeneration treatment, unless the coupe has passed progressive harvesting assessment.

3.4 Potential sawlog retention

Appropriate forest types: Two-aged high quality forests comprising potential sawlogs (20 to 60 cm dbh) and a mature overstorey.

Harvesting method: All mature trees should be harvested and the potential sawlogs evenly retained at 9 to 12 m^2 of basal area per hectare.

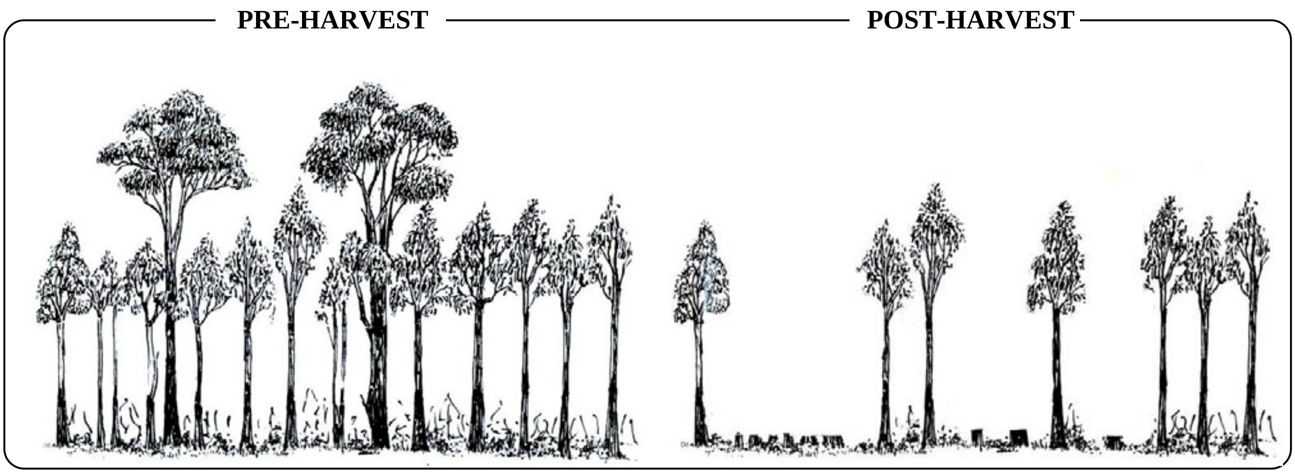
Regeneration treatment: Potential sawlog retention is only undertaken when the stand is adequately stocked. No additional regeneration should be required.

Regeneration survey: A multi-aged survey must be carried out within one year of the regeneration treatment, unless the coupe has passed progressive harvesting assessment.

Potential sawlog retention spacings

For a retained basal area of 12 m²/ha
(for stem densities and spacing at other basal areas see Technical Bulletin No. 5.)

9 m²/ha			12 m²/ha		
Mean dbh (cm)	Stems per ha	Spacing (m)	Mean dbh (cm)	Stems per ha	Spacing (m)
20	286	6	20	382	5
25	183	7	25	244	6
30	127	9	30	170	8
35	94	10	35	125	9
40	72	12	40	95	10
45	57	13	45	75	12
50	46	15	50	61	13
55	38	16	55	51	14



3.5 Clearfelling

Appropriate forest stands: High altitude *E. delegatensis* forests on moderate to steep slopes with a rainforest or wet sclerophyll understorey. The difficulty of ensuring vigorous regeneration on frost-prone sites means that clearfelling is often inappropriate. Do not clearfell when in doubt about the likelihood of successful regeneration establishment.

Harvesting method: All stems are harvested, including non-merchantable trees (culls). Scrub felling or pushing is often used to improve the fuel preparation prior to the regeneration burn.

Regeneration treatment:

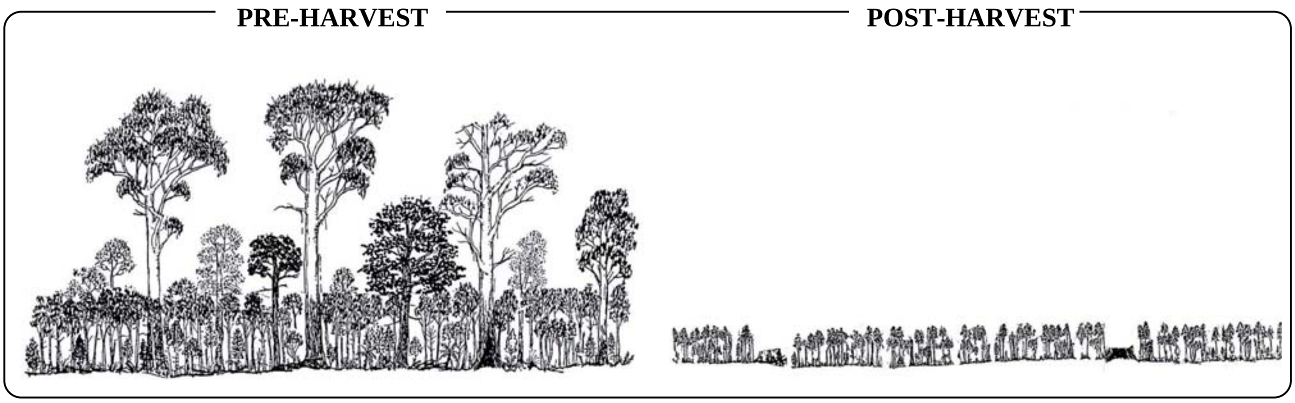
Site preparation: High intensity burn to remove fuels and create receptive seedbed.

Source of regeneration: Aerial sowing. Seed should be sown onto the receptive seedbed as soon as possible after the regeneration burn. Further details on sowing are contained in Technical Bulletin No. 1.

Monitoring and protection: Indicator plots must be established to monitor germination and problems due to frost, drought, insects and browsing damage.

Browsing damage: Browsing transects should be established and monitored, and control of browsing undertaken if required, as prescribed in Technical Bulletin No. 12.

Regeneration survey: A seedling regeneration survey should be carried out in late summer/early autumn in the year following the regeneration burn, as described in Technical Bulletin No. 6.



Part B: Descriptions of *E. delegatensis* Forests

1. Forest Ecology

1.1 The types

Eucalyptus delegatensis occurs over a broad ecological range, varying from an emergent stratum over rainforest, to dry sclerophyll forest where it generally occurs in pure stands or as a dominant species in association with other eucalypts.

The species is common in the highlands of Victoria, New South Wales and Tasmania. The Tasmanian subspecies (*E. delegatensis* subsp. *tasmaniensis*) is physiologically and morphologically different from the mainland forms and was once regarded as a separate species. The mainland form has fibrous bark covering the lower half of the trunk, poor vegetative recovery following damage and is fire sensitive. In contrast the Tasmanian form often coppices from stumps, has fibrous bark which often extends up to the base of the branches in the crown of a mature tree, is more fire resistant as an adult, and can persist as a suppressed seedling in dry sclerophyll understoreys for up to 30 years (Bowman 1984, Ellis and Lockett 1991). These differences give the Tasmanian sub-species much greater silvicultural flexibility than mainland forms.

Although forests dominated by *E. delegatensis* can be divided into different types, there is generally a continuous gradient of change between different sites. The principal environmental parameters most strongly related to forest structure are fire frequency and rainfall (Bowman 1984, Ellis 1985). The detailed distribution diagram of *E. delegatensis* in Tasmania (Williams and Potts 1996) is published in Tasforests Volume 8 page 66.

Major *E. delegatensis* forest types have been identified by Ellis and Lockett (1991) as follows:

Rainforest understorey
Eucalyptus delegatensis emergent over callidendrous and thamnic rainforest occurs where the annual average rainfall is greater than 1250 mm and the fire frequency is low, and in gullies and on sheltered southern aspects where the rainfall is between 1000 and 1250 mm.

Disturbed rainforest understorey
The understorey consists mainly of successional rainforest shrubs, *Tasmannia lanceolata, Persoonia gunnii* and *Coprosma nitida*, and a ground cover of litter, ferns and white grass (mainly *Poa* spp.) where the conditions are climatically suitable for the development of a rainforest understorey (annual rainfall >1250 mm) but succession has been deflected by relatively frequent fires or partial logging.

Shrubby understorey
A 'short prickly' understorey, including *Cyathodes parvifolia, Leucopogon hookeri, Pultenaea juniperina*, and a ground cover of white grass and herbs is prevalent where the annual rainfall is less than 1000 mm.

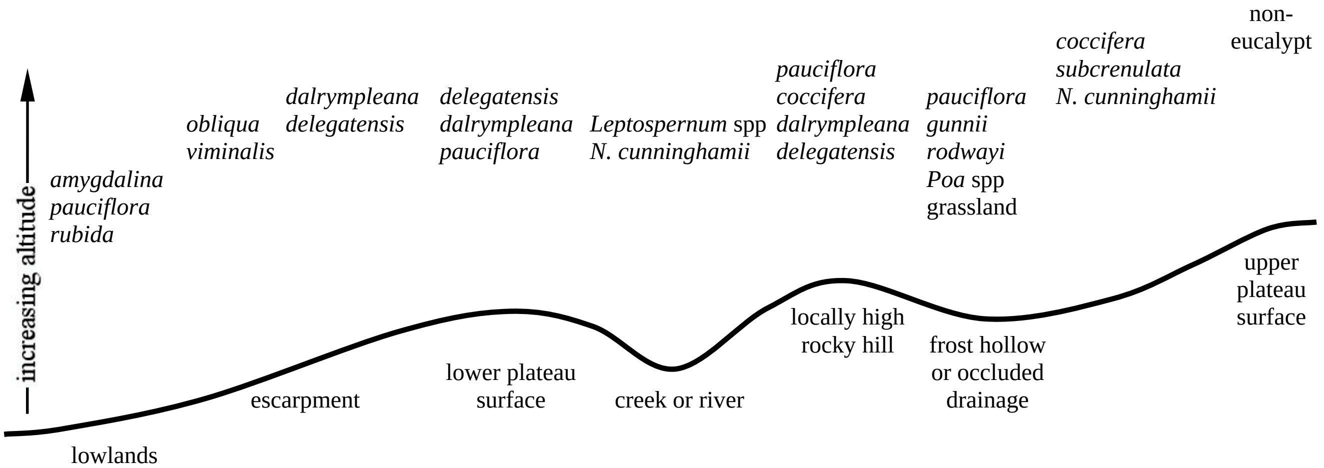
Grassy understorey
There is little or no shrub or small tree understorey and the ground cover consists of white grass with occasional shrubs and patches of ferns at any rainfall where fire is very frequent or in areas prone to cold air ponding.

Wet sclerophyll understorey
Eucalyptus delegatensis may occur with a wet sclerophyll understorey at lower altitudes or on slopes with deep soil at annual rainfalls less than 1250 mm. Shrubs may include *Bedfordia salicina, Zieria arborescens, Olearia argophylla* and *Pomaderris apetala*.

Eucalyptus delegatensis forms alliances with other eucalypt species. Where frost becomes more frequent, *E. pauciflora* and *E. dalrympleana* form an increasing proportion of the stand. On the margins of frost hollows *E. delegatensis* will tend to be replaced by *E. pauciflora* and *E. rodwayi.*

Towards the drier eastern side of the Central Plateau and on drier aspects in the north-east highlands, *E. dalrympleana* and *E. amygdalina* become significant components of the forest. At the forest's lower altitudinal limits, *E. dalrympleana*, *E. obliqua* and *E. globulus* are encountered as co-dominants (Jackson 1973, Duncan and Brown 1985). Figure 5 illustrates the effect of topography on the distribution of *E. delegatensis* and related alliances.

Figure 5. Eucalyptus species dominance changes with topography (after Jackson 1973).



1.2 The environment

The environment contributes to difficult establishment and slow growth through the combined effects of winter cold, frost and summer drought. Regeneration establishment vigour is dependent upon seasonal variations in climate. The timing of frosts and rainfall events is critical to regeneration survival, particularly at the margins of the species distribution, at high altitudes or in drier regions.

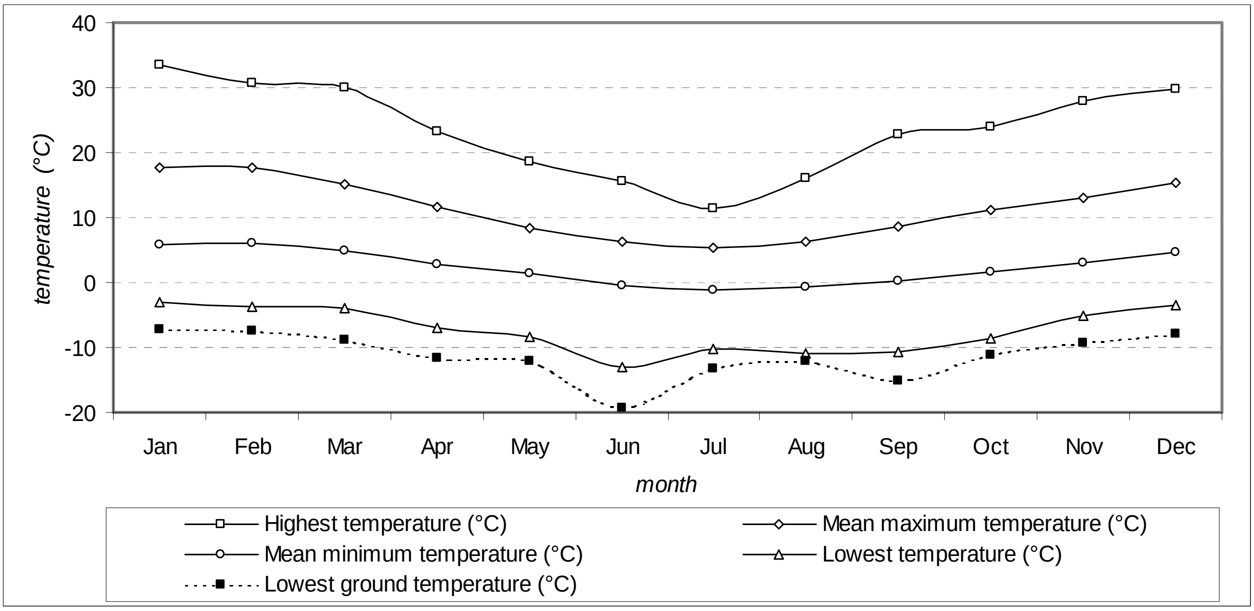
Rainfall

At the dry end of its range, *E. delegatensis* forests occur with *E. amygdalina* as a co-dominant, with a heathy or grassy understorey and the annual rainfall may be as low as 700 mm. At the wet end of its range, where it occurs with a rainforest understorey, rainfall may be as high as 2500 mm. In higher rainfall stands there is typically a distinctive recruitment peak and a lack of regeneration in the younger age classes, whereas stands from the drier sites have a typically multi-modal distribution of tree age. The drier stands may lack a layer of sapling regeneration depending upon recent fire frequency and intensity. Rainfall is generally seasonally distributed with a summer dry period and a rainfall peak in late winter/early spring. On most sites, summer may be typified by a period of two or three months in which growth is limited by a soil moisture deficit. Rainfall is more reliable in the higher rainfall areas and more variable in the lower rainfall areas. Where the annual rainfall is < 1000 mm, severe droughts, which may last for months, occur two or three times a decade.

Temperature

Summers are mild to cool and winters are cold. Average maximum and minimum temperatures for the Central Highlands weather station at Shannon (Lat. 42º10'S, Long. 146º45'E, alt. 940 m) are indicated in Figure 6. Temperatures in the mid-thirties occasionally occur in mid-summer. The months of May to September are typified by maximum temperatures less than 10ºC giving slow growth for this period. Frosts may occur in any month of the year. Between 100 and 200 frosts per year may be experienced. Snowfalls occur in most years but the period of snow lie is typically short. Occasional heavy falls may cause damage to tree crowns and regeneration. For more on the effects of frost and snow on older stands see section 4.

Figure 6. Temperatures: Shannon (HEC) station, 1957-1985.



General definitions

Air temperature is measured in a shaded enclosure (most often a Stevenson Screen) at a height of approximately 1.2 m above the ground. Ground temperature is measured just above the surface of the ground. The overnight temperature, particularly on windless nights, can be lower at ground level than at the level of a Stevenson screen.

Highest temperature (°C) is the highest maximum air temperature observed at the site per month.

Mean maximum temperature (°C) is the long-term average of the daily maximum air temperatures.

Mean minimum temperature (°C) is the long-term average of the daily minimum air temperatures.

Lowest temperature (°C) is the lowest air temperature observed at the site per month.

Lowest ground temperature (°C) is the lowest minimum temperature at ground level observed at the site per month.

Topography

The forests occupy gently undulating plateaus, and the upper slopes of hilly and mountainous country. Over much of its range *E. delegatensis* forests occur relatively independently of aspect except in lower rainfall areas where they may be replaced by *E. amygdalina, E. pauciflora* and *E. dalrympleana* on drier north and west facing spurs (Jackson 1973). On plateau surfaces small changes in topography which result in cold air accumulation are often marked by a transition to sub-alpine grassland (Ellis 1985). *Eucalyptus delegatensis* most typically occurs between 400 m and 900 m but is also found occasionally as low as 150 m and as high as 1200 m (Williams and Potts 1996).

Geology and soils

On the whole, soil parent material does not appear to be an important determinant of forest composition and growth (Ellis and Lockett 1991). These forests occur on parent materials varying from dolerite and basalt to quartzites and schists. The rockiness of soil, whilst not determining the distribution of these forests, greatly influences competition effects following clearfelling. Many of the Central Plateau sites are characterised by permeable surface horizons with impermeable pans in the lower horizons. This causes perched water tables during winter which results in root pruning of trees. There is increasing evidence that soil factors may be important in the growth of regeneration. Nitrogen concentration levels and adverse soil factors have been implicated in the poor growth of seedlings on established grasslands (Ellis *et al.* 1985, McKimm and Flinn 1979, Webb *et al.* 1983). Intra and inter-specific competition for water have been postulated as major causes in the suppression of regeneration in uneven-aged stands (Bowman and Kirkpatrick 1986c, Battaglia and Wilson 1990).

Fire
Fire is an important element in the structure and regeneration of these forests. On the drier sites it is a regular feature. In the wetter stands, fires are less frequent but more severe, although frequent low intensity burning may be reflected in a grassy understorey. Fire, rainfall and biomass production interact to affect stand structure and composition. A model of regeneration recruitment into the drier *E. delegatensis* forests was developed by Jacobs (1955) and refined by Mount (1970) and Bowman (1984). In summary this model proposes that regeneration occurs on the freshly burnt seedbed. These seedlings continue to grow if the canopy of the forest has been sufficiently disrupted to reduce competition. Otherwise they become suppressed seedlings that may be subsequently released following disturbance of the canopy. These suppressed seedlings are fire sensitive because of their thin bark, and are therefore restricted to the fire-free interval for recruitment into the forest canopy. In the moister stands with heavy understoreys fire is less frequent but more intense. Stand age structure is less clearly multi-modal and may reflect only one, two or at most three regeneration events associated with high intensity wildfires separated by up to 100 years. Because of the heavier fuel loads, fire intensities are higher and a longer fire-free interval is required for the successful recruitment of regeneration into the stand.

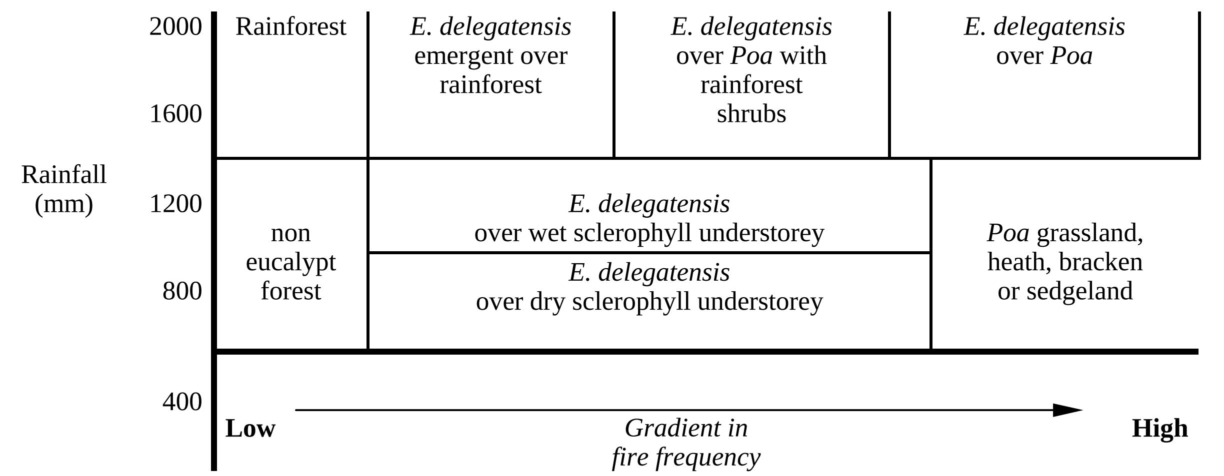
1.3 Ecological relationships

Within its wide ecological range, *E. delegatensis* displays considerable variation in morphological and physiological characters (Boland and Dunn 1985). The matching of genotype and site is therefore important in the management of the forests.

These forests occur within the climatic range of subalpine grasslands. Shifts in the range of environmental factors following deforestation may be sufficient to alter conditions at the regeneration site so that secondary succession occurs along a different path. Trees may be inhibited from invading the site by the occupation of other species, particularly *Poa* spp., and secondary succession may be delayed in accordance with the inhibition model of Connell and Slatyer (1977). If the delay is long enough and grass occupies the site for sufficient time, conditions may become increasingly unfavourable for eucalypts.

Some generalisations about stand structure and understorey composition are diagrammatically represented in Figure 7. It should be remembered that the effects of local cold air and water drainage and soil depth will be superimposed on this model.

Figure 7. Effect of rainfall and fire frequency on stand structure.



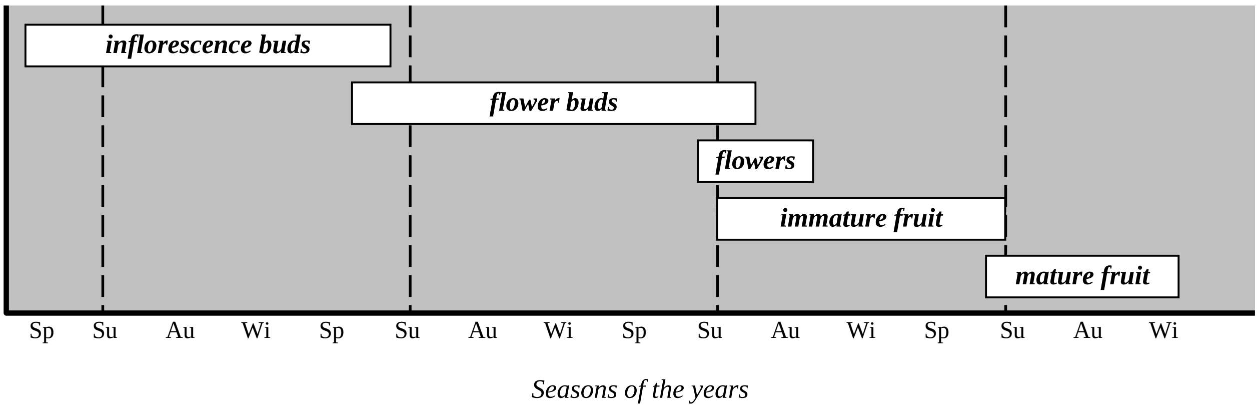
Eucalyptus delegatensis die-back may occur on sites climatically suited to rainforest where a change in burning regime has allowed rainforest to establish beneath the eucalypt canopy. In these stands the eucalypts may die prematurely after 60 - 120 years without fire. It is believed that the primary cause of this dieback is related to changes in soil microbiology with factors such as insect attack and climatic extremes accelerating the process (Ellis and Lockett 1991).

2. Regeneration Requirements

2.1 Seeding habits

From bud formation to seed-fall can take four years. The seed development process is represented in Figure 8 (Cremer *et al.* 1978). Most seed is shed in the third and fourth years (Fielding 1956, Grose 1957, Grose 1960), but the seed from any one crop can probably be shed over a two to four year period. Most of the free seed is shed in the period February to April. However, seed enclosed in capsules, which may be between 30 and 50% of all seed (Grose 1957), is shed mainly in winter. Induced stress may result in more rapid seed shed. For example, ring-barking of trees causes almost all of the seed to be shed within one month (Grose 1957). It is the dominants and to a lesser extent the codominants that are the principal seed producers. Jacobs (1955) found that dominants averaged 232,000 viable seeds each, codominants 28,000 each and suppressed individuals 350 viable seeds each.

Figure 8. The seeding time cycle for *Eucalyptus delegatensis*.



Sp = spring (Sep-Nov) Su = summer (Dec-Feb) Au = autumn (Mar-May) Wi = winter (Jun-Aug)

The number of viable seeds per capsule averages 3.7, but may vary between zero and seven (Grose 1957). Seed viability is normally 100 viable seeds per gram of seed (Scott, 1972). Wasps and weevils may destroy between 7 and 80% (average 20%) of all seed in the capsule (Boland and Martensz 1981, Grose 1957). When seed is moist it is also susceptible to damage by fungi (Grose 1960). The combination of induced secondary dormancy and predation means that seed on the ground only represents the accumulated seedfall of a few months and cannot be relied upon to give regeneration; the only reliable seed is seed stored in tree crowns (Grose, 1960). Little is known about the induction of seed-fall, but it is probably physiological as well as seasonal.

Massive, synchronised seedfall following hot fires has been observed for many eucalypts (Gill 1981) including *E. delegatensis* (O'Dowd and Gill 1984). Seed shed is dependent upon the timing of abscission, and this may be related to drought and heat stress. Only a few seeds shed by *E. delegatensis* are dispersed to distances greater than the height of the tree (Grose 1960). The pattern of seed dispersal is greatly influenced by wind direction (Cremer 1977).

For mainland provenances good seed years occur every two to four years (Grose 1957). This has not been documented for Tasmanian provenances.

2.2 Seedling initiation

Seedling initiation requires the coincidence of viable seed, a suitable seedbed and environmental conditions suitable for early growth.

Seed dormancy and germination

Battaglia (1993) found that the inherent dormancy of *E. delegatensis* seed varied with provenance. Seed from low altitude sites (from south-east Tasmania, below 300 m) showed little dormancy and germinated readily at temperatures above 6ºC. About 50% of seed from cold mid-altitude sites (300 to 700 m) was dormant and required cold stratification prior to successful germination. For seed from the coldest site, primary dormancy was about 60%. Natural seedfall in *E. delegatensis* is in late summer and autumn (Grose 1957), and the fact that half the seed or thereabouts requires cold stratification prior to germination ensures that germination is spread between autumn and spring, and spreads the risk of regeneration failure due to unsuitable environmental conditions (Battaglia 1993).

That primary dormancy varies between seedlots from different provenances is further support for the requirement that for sown coupes, as much on-site and in-zone seed is used as possible. Autumn germinants are not subject to such high winter mortality in Tasmania as on mainland Australia where most sites experience a longer period of snowlie. The optimum sowing times are late summer/early autumn and late winter/early spring. Where conditions are favourable the late summer/early autumn sowings will allow germination and seedling establishment prior to winter. Germinants from late autumn sowings may not develop sufficiently prior to winter and are likely to remain susceptible to frost damage (particularly frost heave). Seed which does not germinate prior to winter will subsequently germinate in spring although there may be significant seed losses due to seed wash and burial (Campbell and Bray 1987), harvesting by insects (Ashton 1979) and fungal attack (Mount 1979). The various pressures on the soil seed store mean that it is likely to be exhausted within one year of sowing (Battaglia 1996). Sowing in late winter/early spring provides an opportunity for a period of natural stratification prior to germination. Late spring or summer sowings may fail if conditions become dry before the seed has germinated.

Seed should only be considered viable for one year after sowing, due to the combined effect of secondary dormancy and seed loss from insect harvesting and fungal attack.

Seedbed

It is widely believed that for regeneration establishment a mineral seedbed is required (Grose 1960, Bowman 1984). For seed to germinate and become established, it must fall on a receptive seedbed. There are three ways that a receptive seedbed may be generated in these forests. The first is by relying on the disturbance associated with logging machinery, the second by deliberately exposing mineral soil by ripping or scarifying and the third by burning. Not only must a seedbed be receptive but conditions at the soil surface must be favourable for germination and germinant survival (Battaglia and Reid 1993a).

The amount of receptive seedbed and the length of time for which the seedbed remains receptive varies with the type of disturbance. From assessment of coupes following logging, the following figures indicate the amount of seedbed likely to be available with the use of each technique:

Technique	Amount of seedbed on coupes
• logging disturbance only	30-50%
• clearfelling and high intensity burning	90%
• scarification or ripping	90-100%

(Battaglia and Wilson 1990)

Grass re-invasion onto disturbed seedbed can be a major impediment to eucalypt establishment. Disturbance, or low intensity fire, which does not destroy rhizomes and root stocks may actively encourage the expansion of vegetative growth. Grass prevents regeneration by physical occupation of the seedbed and by competition for soil, water and nutrients (Ellis *et al.* 1985, Webb *et al.* 1983). By restricting the flow of heat from the ground to the atmosphere (by behaving like a blanket) seedlings on grassy seedbed may be subjected to frosts of higher intensity (Ellis *et al.* 1985, Webb *et al.* 1983). Seedbed treatments influence germinant survival by modifying conditions at the soil surface. High intensity burning may lead to a loss of soil structure in the surface horizons resulting in increased drought stress and frost heave. Burnt seedbeds absorb greater daytime heat into their exposed, blackened surface (Cunningham 1960a) and lose more heat at night due to a lack of insulating vegetation and litter. They therefore have greater temperature fluctuation than unburnt seedbeds at ground level and just above. This greater variation may cause desiccation to small seedlings in hot summers, or frost damage in winter. Intensive soil disturbance by scarification may have a similar effect.

The proportion of disturbed seedbed and the duration of seedbed receptivity is more important to early stocking than environmental conditions at the soil surface. Trials in the Central Highlands have indicated that stocking of burnt seedbeds, due to greater seedbed receptivity, is likely to be 50% higher than stocking on log and leave treatments in both clearfelled and partially-cut stands (Battaglia and Wilson 1990).

2.3 Regeneration establishment

Establishment is that phase of the regeneration process extending from germination until the plant is able to assume dynamic growth (>1.5 m tall) and survive the likely range of climatic extremes.

Growth: Limitations and requirements

Light: Cremer *et al.* (1978) conclude that the most apparent barrier to the regeneration of eucalypts on sites fully occupied by undisturbed tall forest is the low amount of light at ground level. For *E. regnans*, light intensities below 10% of full light intensity are severely limiting to growth, and below 3 to 5% of full light intensity trees are unable to survive (Cunningham 1960b, Ashton 1975a). These results accord with light intensity being the limiting factor to regeneration in the absence of disturbance in such forests.

However, work by Bowman (1984) in the drier (<800 mm), high altitude *E. delegatensis* forest suggests that the suppression of sapling growth is not principally related to shading. Bowman concluded that solar radiation (light) is a secondary factor in controlling productivity and only has a major influence on the dense stands of regrowth which occur in the gaps in the overwood competition, in which case there is a positive correlation between incident solar radiation and sapling size. Bowman and Kirkpatrick (1986b) estimated that a typical high altitude *E. delegatensis* forest allowed 40-60% of available radiation through the canopy.

Water stress: Detailed plant water relations were investigated for Tasmanian provenances of *E. delegatensis* by Webb *et al.* (1983). They found that wilting occurred when xylem water potential fell to between -8.3 and -13.2 bars in unconditioned leaves. Stomatal closure occurred between -7.6 and - 8.3 bars. Growth was found to cease when the seedling xylem water potential fell below -2.3 bars. Additional studies (Battaglia and Wilson 1990) on the Eastern Tiers have indicated that xylem water potentials of between -15 and -17 bars will cause stomatal closure in conditioned leaves. Bowman and Kirkpatrick (1986c) found that in glasshouse studies growth was affected when the gravimetric soil moisture content of a soil fell below 20% with plants becoming exponentially stressed until death occurred around 13%. In the natural environment, summer dry periods can result in trees experiencing water stress for up to three months of the year.

Temperature: The cessation and resumption of winter growth in eucalypts has been found to be closely dependent on the mean maximum daily temperature. Cremer (1975) and Ashton (1975a) working with *E. regnans* found that growth was nil or only slight when the daily maximum temperature fell below 10ºC. Webb *et al.* (1983) found that unhardened leaf tissue could survive undamaged at temperatures down to -6.0ºC , stem tissues down to -8.0ºC , hardened dry leaf tissue to -10.8ºC and hardened wet tissue down to -9.2ºC. Boland and Dunn (1985) noted that inter-provenance variation in frost resistance existed between Tasmanian provenances. Newly emergent seedlings (cotyledons) are the most frost susceptible stage of *E. delegatensis* (Battaglia and Reid 1993b). Late autumn germinants are therefore those that are most at risk from frost damage through the first winter.

Surface temperatures between 50ºC and 55ºC are considered dangerous to seedlings and surface temperatures between 60ºC and 65ºC likely to kill seedlings (Baker 1950). High temperature deaths are often closely associated with drought death. A study in Victoria (Cunningham 1960b) found that 93% of a clearfell and burn coupe had received surface temperatures of 55ºC or over and 44% of the area had received temperatures of 65ºC or over. These occurred on 35 and 5 days respectively.

Nutrients: McKimm and Flinn (1979) found that when *E. delegatensis* was planted following cultivation of a fire-maintained alpine grassland in the Victorian highlands, the seedlings showed a marked response in height growth to nitrogen addition but little to phosphorus or potassium. Ellis *et al.* (1985) showed that the growth response accompanying weed control was partly a response to increased supply of nitrogen since it was accompanied by an increased concentration of nitrogen in leaves, stems and roots of seedlings.

The growth response to $CaCO_3$ addition found by Ellis *et al.* (1985) and Webb *et al.* (1983) can also be explained as a nitrogen fertiliser effect, since the change in pH accompanying the addition of $CaCO_3$ has a major stimulatory effect on nitrification.

Intense grass competition was found to slow the rate of soil nitrogen mineralisation, resulting in a deficiency of nitrogen in eucalypt seedlings, which contributed to growth check (Ellis *et al.* 1985).

Allelopathy and soil microflora and microfauna: Allelopathy and soil micro-organisms have been suggested as causative factors in poor establishment and slow early growth. Results to date have not been conclusive. Keenan and Candy (1983) found that in the north-east of the State, sites of poor early growth were closely correlated with the presence of *Poa* spp., although Ellis *et al.* (1985) demonstrated that this response was largely due to competition for nitrogen. No significant effect was observed following application of leachates obtained from living *Poa* spp. grass or from soil (Webb *et al.* 1983). Intraspecific allelopathy was tested for by Bowman and Kirkpatrick (1986c) using extracts from roots, leaves and litter of mature *E. delegatensis* and they concluded that intraspecific allelopathy was not significant in growth suppression of regeneration.

Browsing: Neilsen and Wilkinson (1994) found that the impact of browsing varied both with the season and with the intensity of browsing. Heavy browsing in late autumn caused the largest reductions in survival and growth. The effect of browsing on overall stocking can also be severe and it may change the composition of vegetation in the long term (Dickinson 1985, Connell and Slatyer 1977). Seedlings are most likely to be defoliated and killed when less than 30 cm in height (Cremer 1969) and browsing is typically worst in the autumn and winter months (Statham 1983). The principal culprits appear to be Bennett's wallaby, pademelons and possums; rabbits can also cause local problems (Statham 1983).

Eucalyptus delegatensis is relatively sensitive to defoliation and one severe defoliation can lead to high mortality (Mazanec 1966). Repeated defoliation, in an environment where other factors may be growth limiting, leads to a reduction in carbohydrate stores and possibly death. The major insect problem is defoliation by the chrysomelid beetle, *Chrysophtharta bimaculata*. The rounding of crowns of severely growth restricted trees may be partly due to coreid beetles, *Amorbus obscuricornis* and *Gelonus tasmanicus* which cause death of terminal shoots. The presence of sooty mould fungus on the stems and branches of many suppressed and growth restricted trees indicates the presence of gumtree scale, *Eriococcus coriaceous*.

Effects of retained trees on regeneration establishment

The level of canopy retention following felling affects regeneration by determining the extent of environmental amelioration and the extent to which resources are released. Research to date has indicated that retained trees reduce the climatic fluctuations beneath the canopy, reduce the rate of growth of regeneration, and increase the average stocking.

Environmental amelioration: Frost damage has been suggested as a major factor in high altitude growth check (Webb *et al*. 1983, Bowman 1984, Nunez and Bowman 1986). The retention of some degree of canopy, either by the deliberate use of shelterwoods or by small group selection, reduces the intensity and incidence of radiative frost, relative to large clearfells. The forest canopy reduces frosting by reradiating heat at night and by reducing longwave radiation loss from the ground. In a shelterwood stand with approximately 50% canopy cover, Nunez and Sander (1981) found a 1.4°C sheltering effect by the shelterwood and, in the absence of cold air drainage, this effect would be higher. The full importance of this degree of sheltering is impossible to determine. However, small changes in environmental conditions at the environmental extremes of a plant’s distribution can be critical to survival and growth. Whilst minimum temperatures in winter may be critically low in both shelterwood areas and clearfell areas, it is the ability of shelterwoods to protect young germinants from unseasonal frosts of mild intensity that is more important. Some estimate of the relative importance of frost can be gained from the close correlation of forest-grassland boundaries and small differences in relief which promote or inhibit cold air drainage.

Clearing size can also significantly affect frost frequency and intensity (Geiger 1966). Small clearings are protected from cooling by the uncut forest edge. In very large openings air circulates freely and convective exchanges may tend to warm the surface layers. At an intermediate size both processes are inhibited, and the uncut forest edge may act as an impediment to air drainage causing damming of cold air (Geiger 1966, Oke 1978), resulting in an even higher incidence of frost than on large clearfells.

Retained trees have also been shown to protect regeneration from lethal high temperatures, although such deaths can be difficult to isolate from deaths from drought. The reduction of surface temperatures by shelterwoods has not been monitored in any Australian studies but has been demonstrated in many American studies (eg Childs, Holbo and Miller 1985, Childs and Flint 1987).

The retention of trees on the site appears to reduce the impact of browsing. Results from a limited study near Lake Echo suggests that browsing of eucalypt seedlings is more severe in a clearfelled area than in a high basal area retention treatment (28 m²/ha). Cremer (1969) working in *E. regnans* postulated that increased browsing following clearfelling is due to increased food and increased accessibility. The retention of trees following harvesting may limit the increase in cover of palatable grasses and herbs, preventing rapid population build-up in recently harvested areas.

Regeneration growth retardation: Retained overstoreys at levels in excess of 12 m²/ha basal area have a pronounced suppressive effect on the growth of regeneration. Figures 9 and 10 illustrate the suppressive effect retained trees have on the height growth of regeneration (after Battaglia and Wilson 1990).

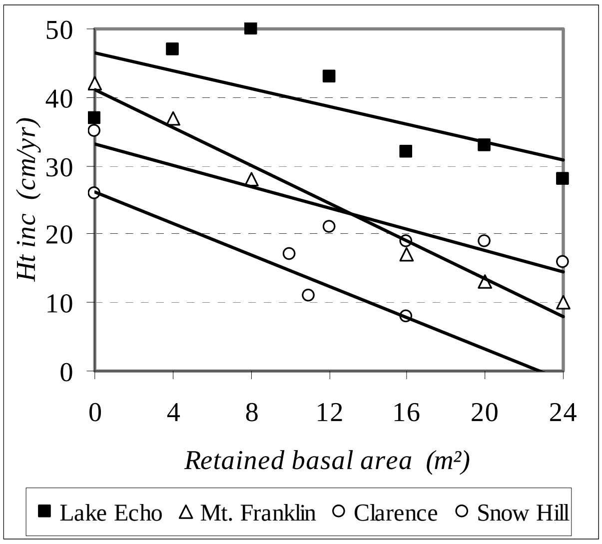


Figure 9. The effect of retained basal area on the height increment of regeneration at four locations.

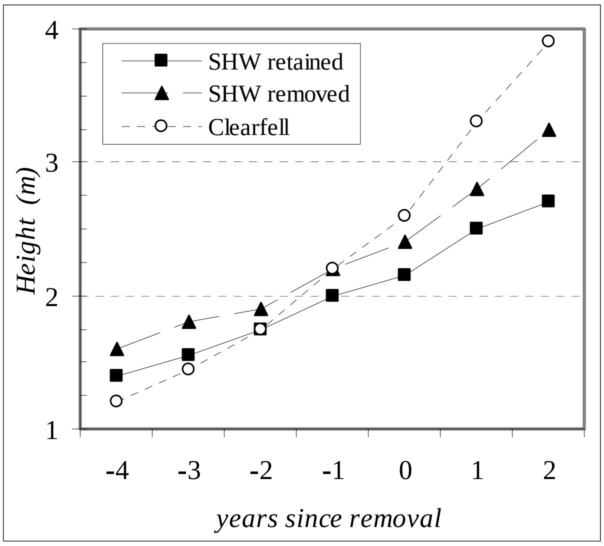


Figure 10. The height increment response to the removal of competition at Clarence Lagoon.

Bowman and Kirkpatrick (1986b) concluded that the principal cause of the growth difference shown above is competition for moisture by mature trees. They found that on a test site at Waddamana soil moisture levels were below that necessary for growth for 12 weeks of summer in a shelterwood treatment (50% basal area retention) compared with 4 weeks in a matched clearfell treatment. On sites where summer rainfall is higher it is likely that the suppressive effect of shelterwoods may be of lesser magnitude. Nevertheless, experience in other forest types (Flint and Childs 1987, Wellington 1984, Dunlap and Helms 1983) supports the general principle of soil moisture competition from retained trees being important in the suppression of regeneration. In a trial across four different sites ranging from high to low rainfall areas, Battaglia and Wilson (1990) showed that regeneration height increment at the wettest site was least affected by retained basal area, and conversely that at the driest site regeneration height increment was most affected. The relationship between the site rainfall and the rate of reduction in height increment was found to be very strong, further supporting the hypothesis that moisture is the limiting factor to growth in many instances.

There has been no conclusive evidence that retained trees act in any other manner to suppress regeneration. Competition for light is not limiting, nor is intraspecific allelopathy a significant factor in the growth of regeneration in these forests (Bowman and Kirkpatrick 1986b, c). They also investigated intraspecific competition for nutrients and concluded that while fertilising (with a NPK fertiliser) increased growth, nutrition did not appear to be the limiting factor to seedling growth where the seedlings were in competition with mature trees. The effect of growth suppression on the success of regeneration following logging is unclear. If regeneration is required to be 1.5 m in height prior to shelterwood removal, growth suppression will add to the length of the rotation. A more serious implication is that seedlings are kept small enough to be vulnerable to environmental influences, particularly the effects of severe drought, for a longer period. To avoid suppression of regeneration beneath a shelterwood, the shelterwood should be removed as soon as possible after the regeneration reaches an average height of 1.5 m.

Retention of trees and regeneration stocking
Retained trees contribute to increased stocking by reducing grass invasion of exposed seedbed and by providing a useful seed tree function. Trials in this forest type have demonstrated higher stocking percents and seedling numbers in shelterwood areas than in clearfell areas, with regeneration recruitment occurring continuously over the first few seasons whilst seedbed receptivity remains (Battaglia and Wilson 1990). Increased recruitment was observed up to retained basal areas of 12 m²/ha, but at higher levels of retained basal areas (16 m²/ha), mortality of regeneration increased during the summer dry period (Battaglia and Wilson 1990). Thus the level of retained basal area in a shelterwood operation is quite critical – below 12 m²/ha and seedling recruitment is reduced, above 16 m²/ha summer mortality and suppression through competition for moisture, is increased. As competition for moisture will increase further as the regeneration increases in size, removal of the shelterwood as soon as practicable, after the regeneration is sufficiently established, is critical to good growth.

2.4 The use of advance growth

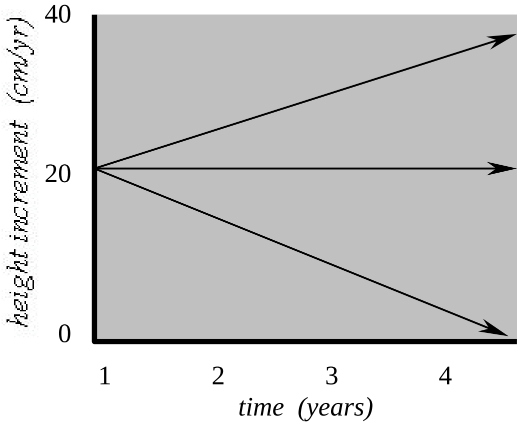
In many instances past logging or wildfires have given rise to a layer of advance growth, or suppressed regeneration, under the canopy. This regeneration can respond well to release from competition even after 20-years of suppression (Ellis *et al.* 1987) with no adverse growth effects. After an initial slow period of growth during establishment, post-logging germinants achieve comparable growth rates to advance growth (Battaglia and Wilson 1990). The only height advantage achieved by advance growth is its extra initial height, and the growth achieved in the period immediately following logging. The latter may not be all that significant as experience from the Central Highlands and Eastern Tiers indicates that the full growth potential of advance growth is not achieved until a growing season or two after release from competition (Battaglia and Wilson 1990).

Mortality of suppressed advance growth following competition release is low (Ellis, pers. comm.) so advance growth provides an assured supply of regeneration if it is present before logging and if it can escape destruction during logging and/or intensive site preparation such as scarification or burning. Damage from logging may occur during the initial harvest (shelterwood retention), or during the shelterwood removal. Ellis *et al.* (1987) reported very little damage to retained material in a logging trial near Waddamana. In contrast, a Forestry Tasmania trial designed to look at the effect of shelterwood removal found that between 20 and 30% of all advance growth present could be lost and that unstocked gaps would be increased. This trial found that damage was independent of height of advance growth up to at least 3 m. If stocking of advance growth is high, or options for felling to avoid advance growth patches exist, loss of advance growth during logging need not be a serious problem. However, the problem can become acute when advance growth stocking is uniformly low.

2.5 Early growth patterns

Establishment following clearfelling
The general pattern for establishment following clearfelling appears to be an initial period of slow growth lasting from one year to ten or more years in which the seedling struggles to occupy the site. This is followed by a period, possibly following a succession of favourable climatic and environmental conditions, in which growth dramatically increases and continues at a rapid, but relatively constant rate. The first period is characterised by height growth of between 0 and 30 cm per year, often less than 10 cm per year. While receptive seed beds and viable seed are available, seedling turnover is very high. Mortality is offset by new germinants which may constitute 30-50% of seedlings, but total stocking gradually declines. Growth during this period is probably concentrated in the roots in a similar way to that recorded in other forest types (Cremer 1975, Ashton 1975b). High mortality at this stage is probably due to the combined action of drought, frost and browsing. The effects of frost and browsing result in many seedlings assuming a multi-stemmed form. While seedling growth is in this phase the ultimate occupation of the site is uncertain. A trial in north-east Tasmania, in which the growth on clearfelled coupes at high altitudes has been monitored, has indicated a number of possible development paths (Figure 11).

Figure 11. Possible seedling development paths for three growth regimes.



Path 1. A site where eucalypts have occupied the site and are growing well.

Path 2. A site on which the future is still uncertain or where the site is breaking into tree clumps and

Path 3. A site where eucalypts are losing site dominance and are going into severe check.

Growth check

Growth check is an extreme form of growth impediment resulting from the complex interaction of adverse environmental conditions. No one factor alone can be given as the cause of growth check. However, frost and severe competition from dense *Poa* grass have been implicated as major factors (Webb *et al.* 1983, Ellis *et al.* 1985). 'Growth check' is not an "on-off" condition, nor a diagnosable disease. It is the growth response to adverse growing conditions which in any one year may be caused by the independent or interactive effects of many factors including frost, browsing, grass competition, soil nutrition or insect attack.

Growth checked trees tend to have bushy rounded crowns with a loss of apical dominance. They have smaller, thicker and more leathery leaves than vigorously growing individuals and heavy infestation of insects and fungi. Trees may be growing slowly and exhibit all or none of these attributes. Growth check as a condition may persist for periods from a few years to greater than 20 years. On some sites under favourable conditions, seedlings have recovered from check and resumed reasonable growth rates.

The forests in which the most acute problems are expressed are largely on sites close to the ecological extreme of the species. On these sites, where early growth rates appear disappointingly slow, one must be careful that expectations are not unduly biased by the high standing volumes of the surrounding forests. High standing volumes do not necessarily equate with easy establishment or high growth rates. It is to be expected that the nearer to the ecological extreme of a species one gets, the more uncertain will be regeneration. At its ecological limit a species will be dependent upon the coincidence of the periodic occurrence of more favourable climate and the appropriate regeneration site conditions (Muelder 1959). At these limits it can also be expected that small differences about threshold values will produce significant differences in growth, and may even mean the difference between survival and replacement by other vegetation types.

3. Growth and Yield

3.1 Volume increment

The total merchantable volume of existing stands ranges from 50 to 500 tonnes per ha. Forests carrying less than 70 tonnes per ha would generally be regarded as non-commercial. Typical yields from clearfelled virgin stands are 300 t/ha of pulpwood and 70 m³/ha of sawlog for the better quality forests (ie. those of 41 m or more in height) and 220 t/ha of pulpwood plus 30 m³/ha of sawlog for lower quality stands. The majority of current operations are situated in previously cut over stands in which lower sawlog yields could be expected. Some indications of growth rates of stands to be expected in the next rotation have been derived from plots established in patches of well-stocked, even-aged natural regrowth of various ages (Table 2). Although the data are few, they do suggest that mature stand height alone is not necessarily a good indicator of growth rates. Good sites at high elevation may produce large trees and high stand volumes, but over longer rotations than those needed at lower elevation. In general, MAIs of about 5 m³/ha/year would seem to be a reasonable expectation from well-managed forest during a rotation of 80 years.

Table 2: MAIs from even-aged regrowth plots (from Ellis and Lockett 1991)
(gross bole volume to 10 cm top – m³/ha/year)

Elevation	Mature Stand Height <41 m	Mature Stand Height >41 m
600 – 700 m	6.3	9.4
700 – 800 m	7.4	
800 – 900 m	5.4	7.5
>900 m	4.5	-

Most of these forests are uneven-aged before felling. Clearfelling and burning of these multi-aged stands sacrifices all potential sawlogs that are less than the minimum saleable size at the time of harvesting. A study by Ellis *et al.* (1987) has indicated that the sawlog yield in these forests can be significantly increased by uneven-aged management. They found that total volume production of sawlog over a rotation of 80 years could be increased from approximately 70 m³ per ha (ie less than 1 m³/ha/year) to an annual increment of 2.3 m³ per ha using uneven-aged management. By applying a regime of repeated cutting on an approximate 25-year cycle, they suggest that production could be increased even further.

4. Damage to Older Stands

Except for occasional cataclysmic events, such as fires or extreme frosts, once trees have reached the pole stage mortality is low in these forests (Ellis *et al.* 1987). Damage, however, may be caused by a number of factors including insects, wind, snow and fungal attack.

4.1 Fire

Mature trees in these forests are relatively fire resistant but the understorey saplings are fire sensitive. Stem death is infrequent except in the wetter forests where heavy understoreys increase fire intensity. Generally death is caused by stem failure following recurrent damage to the base (Bowman 1984). Smaller stems with little thermal insulation because of their thin bark may be killed by cambial death caused by high temperatures. Where stands have been repeatedly burnt, many trees will have stem and bole damage, and kino-vein formation may also occur. Fire intensity and fuel loads and frequency are determined by the interplay of rainfall and understorey biomass. Long unburnt stands with a rainforest understorey may have fine fuel loads of 30 or 40 tonnes per ha, whereas those stands with a grassy understorey may have a fine fuel load of less than 10 tonnes per ha many years after the last fire.

4.2 Frost

Infrequent but severe frosts may result in the wholesale death of mature stands. The explorer Calder told of a severe frost in 1850 which killed large tracts of forest on the Central Highlands. The return frequency of such frosts is not known. They may be an important, albeit infrequent, influence on forest structure in the subalpine zone in a similar manner to the infrequent high intensity fire in wet forest. Once trees are greater than 1 to 2 metres in height they may be considered relatively immune to damage from frosts of 'normal' severity. Davidson and Reid (1985), examined the effect of a single intense frost event on mixed species stands (including *E. delegatensis*) at Snug Plains, and found that the frost event caused marked changes in the species dominance patterns even though only a few individuals were actually killed. Such effects demonstrate the importance of retaining shelterwoods on sites that may be subject to intense frosts.

4.3 Snow

Cremer (1983) made some observations about snow damage to *Eucalyptus delegatensis* forests in the ACT. His observations are summarised below:

- snow may cause damage to regrowth less than 4 m in height by bending and breaking of stems, although generally most stems bent by snow are undamaged,
- mature trees may have crowns damaged by limbs breaking under snow weight,
- the worst snow damage occurs with wet snow, in relatively sheltered locations, and when snow loads persist during violent winds, and
- epicormic shoots and secondary crowns are particularly susceptible to snow damage because they are weakly attached to stem wood.

4.4 Windthrow

The vertical development of roots in many stands is restricted by high water tables or impermeable subsurface horizons. Typically such trees form a large root plate that may extend no more than a metre below the surface. Consequently windthrow is a relatively common phenomenon in these forests, particularly when stands have been opened up by thinning or partial cutting.

4.5 Insects

Insect defoliation can dramatically reduce height and diameter increment (Mazanec 1966, 1968). Repeated defoliations may occur in successive years and may deplete tree carbohydrate reserves, cause loss of height and diameter increment and promote kino vein formation. Chrysomelid leaf beetles are the main defoliators in Tasmanian forests. The termite *Porotermes adamsoni* is a relatively common cause of damage in these forests. Infestations begin in damaged tissues such as fire scars and spread, giving a hollow core or pipe in the tree (Elliott and Bashford 1984). Fungal heart rot is usually associated with termite damaged tissue.

4.6 Fungal diseases

The leaf infecting fungus, *Mycosphaerella cryptica*, can cause significant defoliation and shoot dieback in vigorously growing, young trees in moist situations. It is uncommon, however, for severe infection to persist into older and taller regeneration. Regeneration on clearfelled areas with poor cold air drainage can sustain heavy levels of leaf infection by fungi such as *Aulographina eucalypti* and *Pachysacca samuelii*. It is probable that such infections are largely in response to poor plant vigour due to unfavourable sites and/or environmental conditions. Amelioration of plant vigour by the use of shelterwoods in such areas would be expected to reduce infection levels.

5. Silvicultural Management

In general these forests allow greater silvicultural flexibility than almost any other Tasmanian forest type. Under appropriate silvicultural regimes regeneration is only rarely a problem. Important principles in the management of this forest type are:

5.1 Existing stand structure

The choice of silvicultural system will usually be dictated by past events. The long history of logging and variations in fire frequency have resulted in a mosaic of small stands of differing structure. Forests can be managed using even-aged or uneven-aged silvicultural systems. Many stands with an even-aged structure can be converted to uneven-aged management, and likewise uneven-aged forests can be converted to even-aged management, albeit with the loss of potentially merchantable sawlogs.

5.2. Environmental factors

The environment of these forests is typically harsh with a short growing season, and subject to considerable annual variation. Any one season is likely to contain some climatic extreme, whether it be a drought, an unseasonally hard frost or heavy snowfall. In consequence the regeneration niche should be viewed as occurring in both space and time, and not merely the conditions that prevail at the site immediately following harvesting. The interplay of factors such as the occurrence of seedfall or the frequency and timing of frosts is as important in forest establishment as the nature of the seedbed. The selection of the optimum silvicultural system is based on expanding this regeneration niche. It should maximise the time period over which suitable seedbed, viable seed and favourable conditions may coincide, and it should maximise the available growing season so that seedlings are less vulnerable to environmental vagaries.

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