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Lowland wet eucalypt forests

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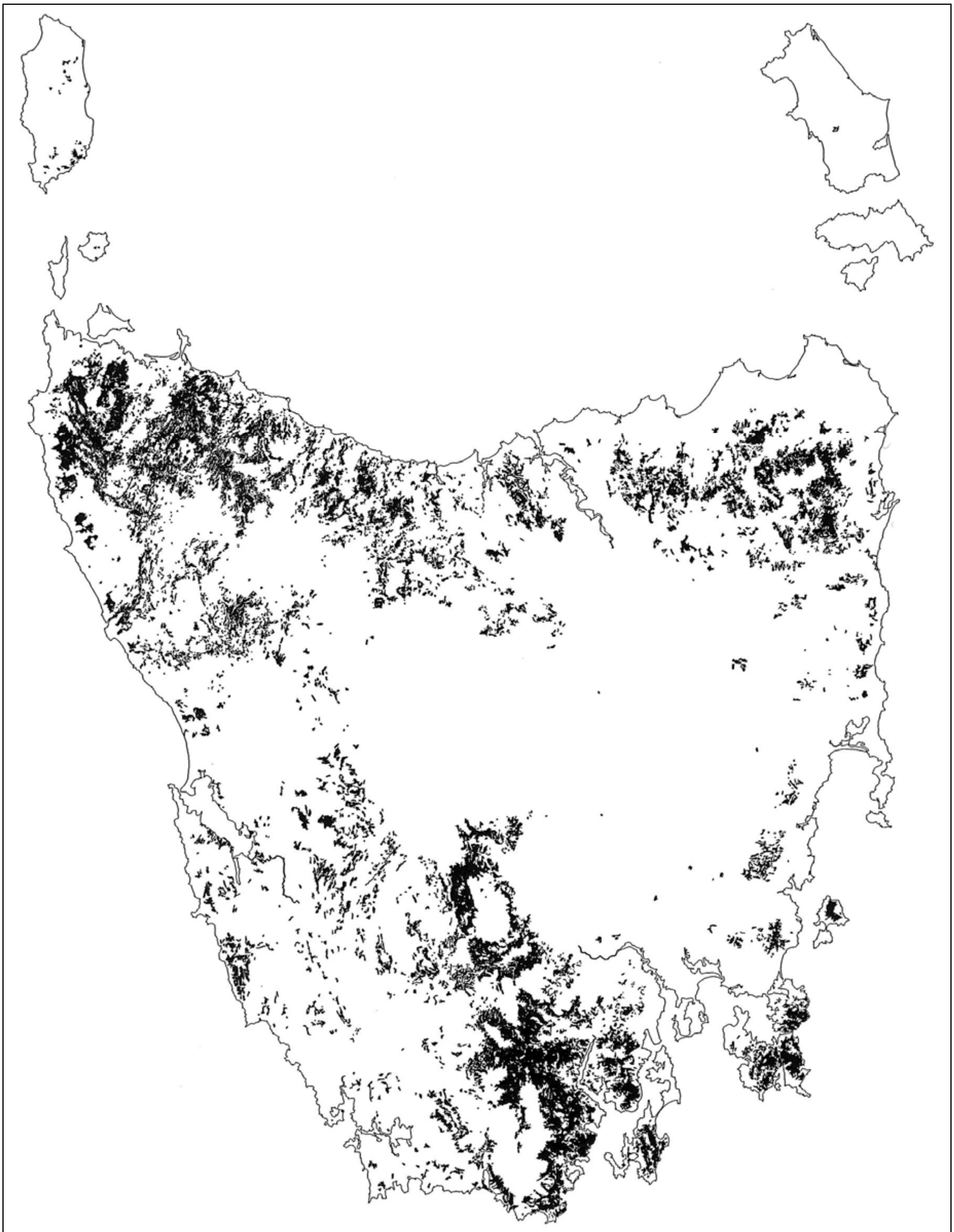
Part A Silvicultural Prescriptions for the Management of Lowland Wet Eucalypt Forests

1. Introduction

Lowland wet eucalypt forests (LWEF) occur extensively throughout Tasmania (see Map 1), from sea level to 600 m asl, in areas of moderate to high rainfall and on all but the poorest soils. They constitute about 18% (600 000 ha) of the State's forested area (3.3 million ha); about 52% of this area occurs within State forest, 33% is reserved and 15% is privately owned (Forest Practices Authority 2007).



Map 1. Distribution of lowland wet eucalypt forests in Tasmania, CRA Vegetation Map (PLUC 1997).

Lowland wet eucalypt forests characteristically have dense multi-layered understoreys which can be dominated by rainforest species (called mixed forests), or by a variety of broad-leaved tall shrubs and small trees (called wet sclerophyll forests). The term wet eucalypt forest includes both mixed forest and wet sclerophyll forest (Kirkpatrick *et al.* 1988).

Photo 1 Mixed forests have understoreys which are dominated by rainforest species.

Photo 2. Wet sclerophyll forests have broad-leaved shrubs and trees.

Wet eucalypt forests have been heavily exploited since white settlement of Tasmania (Kostoglou, 1996). In wood production terms they are amongst the most productive eucalypt forests in Australia. Huge volumes of timber for a variety of uses have been recovered, and significant areas have been cleared for agriculture. PLUC (1996a) estimated that nearly 40% of the taller wet eucalypt forests have been cleared since white settlement.

Lowland wet eucalypt forests play a major role in water production and stream protection, as well as providing a home to many species of native wildlife. They are also highly valued for their scenic and recreational qualities.

2. Silvicultural Considerations

1. Lowland wet eucalypt forests generally comprise one or more cohorts of overstorey eucalypts each of which have established following a past disturbance, usually wildfire. The forests are tall, commonly being more than 40 m high and sometimes reaching 90 m. They have a dense understorey and there is usually no advance growth present.

2. Harvesting of the overstorey eucalypts and disturbance of the dense understorey results in heavy slash loads which must be removed by fire or by mechanical means before eucalypt regeneration can establish. Eucalypt seedlings establish more prolifically and grow faster on burnt seedbed than on disturbed but unburnt seedbed. Mechanical disturbance can cause compaction of the surface soil.

3. Successful regeneration requires receptive seedbed, an adequate supply of high quality seed, high light levels, reduced levels of overstorey competition and freedom from heavy frosts, drought and excessive damage by insects and browsing animals.

4. Safety considerations preclude the use of partial harvesting systems in these forests. The size of the trees alone limits the opportunity for safe directional felling amongst retained trees.

5. The high light requirements of young eucalypt seedlings for establishment and early growth means that the minimum opening size is equivalent to about two tree heights. In 40 m tall forest, openings need to be at least 80 m wide to facilitate successful burning of the harvesting debris.

6. Clearfelling, followed by an intense regeneration burn and aerial sowing, is currently the most commonly prescribed system for harvesting lowland wet eucalypt forest. This technique meets all the major silvicultural considerations; the heavy fuel load is removed, a receptive seed bed is prepared and the ashbed effect maximised, the amount of sunlight reaching the seedbed is maximised, soil damage is minimised and the future crop can be consistently and successfully established.

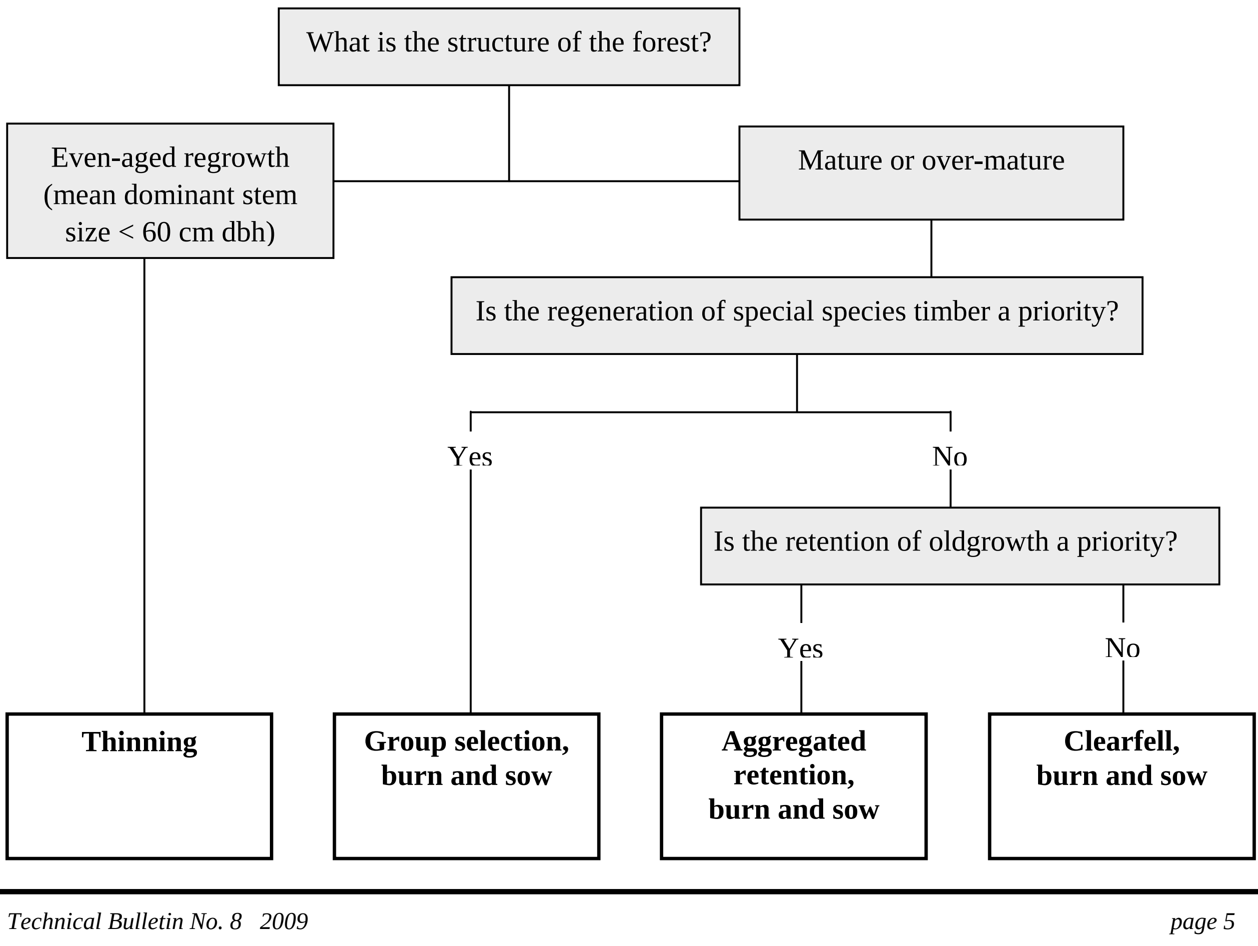
7. Aggregated retention is the most appropriate system for harvesting coupes that contain a significant proportion of oldgrowth forest (greater than 25% by area), and where the priority is on retaining greater structural and biological diversity into the regenerating stand.

8. Aggregated retention is one form of variable retention, the other being dispersed retention. In variable retention systems, forest influence must be retained over the majority of the harvested area. This measure is also used to distinguish variable retention systems from clearfelling. Typically in clearfells the majority of the harvested area is not under forest influence.

9. In wet eucalypt forests rich in special timbers, where the priority is successful regeneration of the special species timbers (myrtle, blackwood, leatherwood, celery-top pine and/or sassafras), group selection may be the most appropriate system.

Silvicultural systems currently or potentially applied to lowland wet eucalypt forests in Tasmania are summarised in Section 3 and described in further detail in Part B of this bulletin. Guidelines for the selection of harvesting methods and regeneration treatments are provided in Figure 1.

Figure 1. Selection of the appropriate silvicultural system for lowland wet eucalypt forest.



3. Silvicultural Systems

3.1 Clearfelling

Appropriate forest stands:

Lowland wet eucalypt forests (i.e. both mixed forests and wet sclerophyll forests) typically dominated by *E. obliqua* or *E. regnans*.

High altitude *E. delegatensis* forests on moderate to steep slopes with a rainforest or wet sclerophyll understorey.

Lowland dry eucalypt forests on steep slopes, which are to be harvested using cable machines.

Harvesting method: All stems are felled, 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 creation. 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.

Further details: See Technical Bulletins No. 2 *Eucalyptus delegatensis* forests and No. 3, Lowland dry eucalypt forests.

3.2 Aggregated retention

Appropriate forest types: Wet eucalypt forest coupes where greater than 25% of the coupe by area is oldgrowth. Aggregated retention is currently recommended for use only in ground based operations.

Harvesting method: Coupes must be designed such that the majority of the coupe is under the influence of forest that is planned to be retained unharvested for at least the next rotation. This is usually achieved by retaining edge or island aggregates that are located where possible in areas of ecological value. Aggregates are maintained as undisturbed as possible during the harvesting, whilst the remaining area of the coupe is harvested.

Regeneration treatment:

Site Preparation: Moderate intensity burn to remove fuels and create receptive seedbed. The aim of the burn should be to achieve the best seedbed possible, whilst also minimising the impact of the regeneration burn on the aggregates. Firebreaks should be prepared to the minimum practical width necessary for access if required for mop-up operations and browsing control.

Source of Regeneration: Seed should be sown onto the receptive seedbed as soon as possible after creation. Further details on seed and sowing are contained in Technical Bulletin No. 1. Seedcrops around the harvested area of the coupe should be assessed prior to the regeneration burn. Where the seedcrop is adequate, natural seedfall may be sufficient to regenerate the coupe.

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.

Further details: See the Variable Retention manual for advice on planning and harvesting aggregated retention coupes. For guidance on maximising biodiversity outcomes see Baker *et al.* (2009).

3.3 Group selection

Appropriate forest types: Wet eucalypt forests rich in special species timbers.

Harvesting method: The broad aim is to harvest about 30% of the coupe at each of three stages, such that by the end of the rotation up to (but probably less than) 90% of the coupe has been harvested, with at least 10% of the coupe retained for maintenance of late successional species and structures.

- The emphasis should be on harvesting mature trees
- >70% of forest canopy should be retained after each harvest
- Potential crop trees should be retained undamaged
- Harvest fairways approximately 80 m, or about two tree lengths, wide
- Leatherwood rich patches should be retained undamaged.
- Individual sound and safe eucalypts may be retained within the fairways, where practicable and at the contractors discretion, at an approximate spacing of two tree lengths to improve aesthetics, seed source, habitat and longer rotation eucalypt sawlog.

Regeneration treatment:

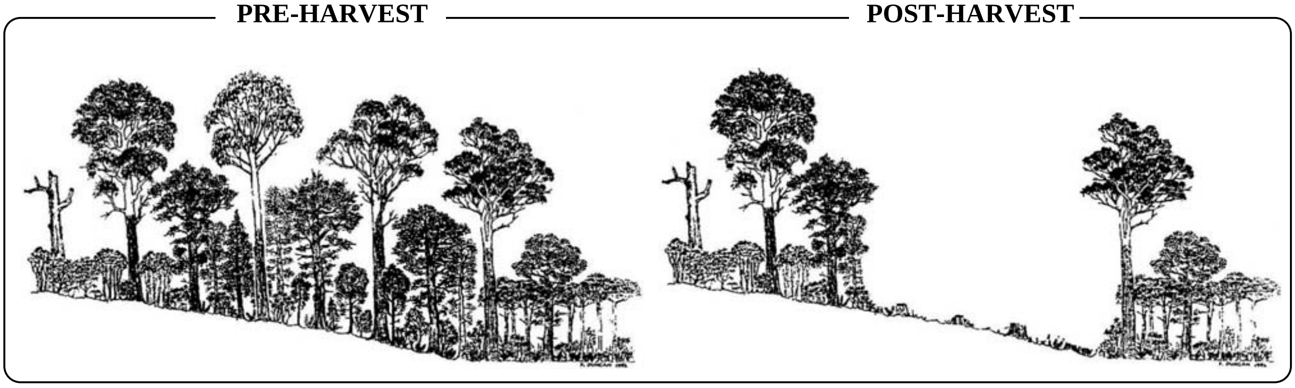
Site Preparation: Moderate intensity burn to remove fuels and create receptive seedbed. The aim of the burn should be to achieve the best seedbed possible, whilst also minimising the impact of the regeneration burn on the surrounding forest. Firebreaks should be prepared to the minimum practical width required for access if required for mop-up operations and browsing control.

Source of Regeneration: Eucalypt seed should be sown onto the receptive seedbed as soon as possible after creation. Further details on seed and sowing are contained in Technical Bulletin No. 1. Seedcrops around the harvested area of the coupe should be assessed prior to the regeneration burn. Where the seedcrop is adequate, natural seedfall may be sufficient to regenerate the coupe. The rainforest species should regenerate adequately from natural seedfall and ground-stored seed.

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 treatment, as described in Technical Bulletin No. 6.



3.4 Thinning

Appropriate forest types: Even-aged regrowth with high stocking levels on sites with good growth potential.

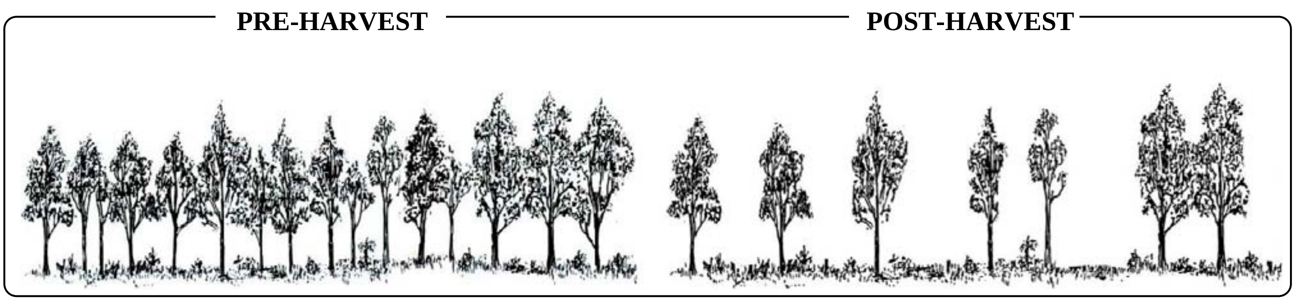
Harvesting method: Thinning is conducted 'from below', where the smaller trees are removed and about one-half the original basal area is retained after thinning. Methods and prescriptions vary according to site factors and the age and quality of the regrowth.

Pre-commercial thinning (PCT) is generally undertaken at age 10 to 25 years using stem injection of herbicide. Areas selected for PCT should have a stand basal area greater than 20 m^2/ha and at least 1000 stems per hectare larger than 10 cm dbh. After PCT the stand should comprise at least 500 crop trees with a basal area of at least 12 m^2/ha. The intention is to maximise the early growth of the best stems (the crop trees) and increase the viability of a subsequent commercial thinning.

Commercial thinning (CT) is generally undertaken at age 25 to 45 years. Coupes selected for CT should have a stand basal area greater than 32 m^2/ha and at least 500 stems per hectare larger than 17 cm dbh. After thinning the stocking will be reduced to between 150 – 250 stems per hectare, depending on the initial structure of the stand, and the retained basal area should be at least 16 m^2/ha. Retained trees must be undamaged, well-formed, vigorous trees with good growth potential.

Regeneration treatment:
No additional regeneration should be required as the stand should be maintained in a stocked condition. Minimising damage to retained stems is critical. Stocking should be monitored throughout the thinning operation.

Further details: See Technical Bulletin No. 13, Thinning regrowth eucalypts.



Part B: Descriptions of Lowland Wet Eucalypt Forests

1. Forest Ecology

1.1 The characteristics of lowland wet eucalypt forests

Lowland wet eucalypt forests (LWEF) are characterised by a tall (> 34 m) open forest canopy over a dense secondary layer of small trees and tall shrubs. The secondary layer may be dominated by rainforest species (as defined by Jarman and Brown (1983), including myrtle, sassafras, celery-top pine and leatherwood), in which case the forest is considered mixed forest (Gilbert, 1959), or it may be composed of a variety of broad-leaved shrubs (e.g. dogwood, tallowwood, blanket bush, musk) in which case the forest is considered wet sclerophyll forest. The term wet eucalypt forest encompasses both mixed forest and wet sclerophyll forest (Kirkpatrick *et al.* 1988).

The dense understorey, the often dense ground layer, and the heavy litter loads in lowland wet eucalypt forests prevent the continuous regeneration of shade intolerant species, including eucalypts, as happens in drier and more open eucalypt forests. Regeneration in wet eucalypt forest is reliant on disturbance to open the canopy, prepare a mineral soil seed bed and initiate seedfall. In nature this disturbance is usually wildfire. Because regeneration is usually initiated by wildfire, wet eucalypt forests are even-aged only in the sense that a cohort of regeneration arises from the same disturbance event. As wildfires are rarely intense enough to kill the overstorey, more than one age-class of tree is usually present in the same stand (Turner *et al.* 2009).

1.2 The distribution and floristics of lowland wet eucalypt forests

Distribution

Lowland wet eucalypt forests in Tasmania are capable of occupying a wide range of sites. The distribution of LWEF is shown in Map 1. Hickey and Savva (1992) indicate that up to 20% of Tasmania's wet eucalypt forest has an understorey dominated by rainforest species (i.e. is mixed forest).

Communities

Lowland wet eucalypt forests are classified into two broad forest types; wet sclerophyll forest and mixed forest. For management purposes, both types have been further subdivided on the basis of their dominant eucalypts. Table 1 (overleaf) summarises the major LWEF types in Tasmania, and their general characteristics.

Mixed forests

Mixed forests have many similarities with rainforests both in their vascular and non-vascular flora, and in many cases mixed forest understoreys can be ascribed to the rainforest groups of Jarman *et al.* (1984). Particular dominant eucalypts tend to be associated with particular understorey types (Table 2). Mixed forests can vary structurally, from tall forests exceeding 90 m in height with closed rainforest understoreys, to short forests in the subalpine zone with open montane rainforest understoreys.

Table 2. Rainforest understorey groups and commonly associated dominant eucalypts (from Duncan, 1985).

Rainforest group	Dominant overstorey eucalypts
Callidendrous	*E. obliqua, E. regnans, E. delegatensis, E. brookeriana, E. dalrympleana*
Thamnic	*E. brookeriana, E. delegatensis, E. johnstonii, E. nitida, E. obliqua, E. subcrenulata*
Implicate	*E. nitida*

Table 1. Major lowland wet eucalypt forest types in Tasmania and their general characteristics (after Kirkpatrick *et al*. 1988 and Wells and Hickey 1998).

Dominant eucalypt	General distribution	Environment	Common co-dominants in wet forests	Height of mature eucalypt canopy (m)	Other comments
obliqua	Widespread	Highly variable	AMY BRO DEL GLO REG VIM	10-80+	Occurs as pure stands over much of its range. Also a common dominant of dry forests
delegatensis	Widespread at moderate altitudes	Highly variable	OBL VIM DAL	20-70+	Common in wet & dry forests at medium altitudes into subalpine zone
regnans	Uneven distribution	High rainfall on fertile sites	Normally in pure stands but also with OBL and DEL	30-90+	Restricted to very tall wet forests
brookeriana	NW & E Tas	Typical in gullies and the margins of swamp forests	OBL	30-60	Not widespread
dalrympleana	N, E, & SE Tas	Most common on dolerite and granite	DEL	20-40+	Rarely occurs in pure stands
globulus	E and SE Tas Occasional in W. Bass Strait Islands	Most common in the drier regions of Tas	OBL	20-60	Common dry forest dominant. Rarely extends into mixed forest
nitida	W & SW Tas	Predominantly on infertile substrates	Normally occurs as pure stands	8-60+	Significant height variation
ovata	E Tas with some outliers in the NW	Generally concentrated along drainage lines		<40	More common in dry sclerophyll forest

Wet sclerophyll forests

Wet sclerophyll forests can also vary enormously in structure. On the nutrient-poor substrates of the west and south-west, *E. nitida* wet sclerophyll forest can be very reduced in stature, intergrading with *E. nitida* wet scrub as fertility and drainage decrease. On better quality sites with high annual rainfall and well drained deep fertile soils, wet sclerophyll forests, particularly those dominated by *E. regnans* and *E. obliqua*, can attain heights equal to the tallest mixed forests. The tallest recorded individual of *E. regnans* was measured last century in Victoria at 110 m (Ashton 1981b).

Wet sclerophyll forests have a distinct layered structure with the tallest stratum being dominated by an open eucalypt canopy. Beneath this is often a sub-stratum of secondary trees with silver wattle and blackwood being the most common. An understorey of broad-leaved shrubs typically lies underneath the tree layers in a zone 2-15 m from the ground layer. The shrub zone is normally single layered and dense, precluding continuous regeneration of species such as eucalypts, which are shade intolerant (Jacobs 1955, Gilbert 1959, Ashton 1976a). Some of the more common shrub species associated with wet sclerophyll forests include dogwood, blanket bush, dolly bush, musk, lancewood and stinkwood. Where drainage is impeded, tea-tree and/or paperbark are often prominent in the shrub layer.

Kirkpatrick *et al*. (1988) and Jackson (1981) give comprehensive accounts of species commonly found in wet eucalypt forests.

A ground layer, often rich in ferns forms the third major stratum in wet sclerophyll forests. Intermixed with ferns are a variety of sedges (e.g. cutting grass and sword sedge), herbs, climbers, orchids, bryophytes and lichens. However the diversity of non-vascular species is generally less than for mixed forests (G. Kantvilas, pers. comm.).

In the shorter wet eucalypt forest communities where either drainage is poor or fertility and/or moisture availability is low, species common to both wet and dry forests can be found. Examples of understorey shrub species in this category include prickly beauty, dusty daisy bush, guitar plant, tea-tree, paperbark, heath and native willow.

Lowland wet eucalypt forest boundaries
Wet sclerophyll and mixed forests are not necessarily discrete forest units, but more commonly intergrade with other forest and scrub types. Mixed forests form a continuum with rainforests following a gradient of increasing time since the last fire. Where drainage is impeded and soils infertile and poorly developed (as often occurs in western Tasmania), wet sclerophyll forests form a continuum with wet scrubs dominated by sclerophyllous shrubs including tea-tree and paperbark. As moisture availability decreases wet eucalypt forests intergrade with dry sclerophyll forests through an array of different communities (Jackson 1981, Duncan 1985). With increasing altitude the distinction between wet and dry forests is also blurred. Areas receiving relatively high rainfall may contain eucalypt forests with predominantly scleromorphic understoreys.

Further information on LWEF can be found in Kirkpatrick *et al.* (1988) (communities and floristics of wet eucalypt forests in Tasmania), Wells (1991) and Wells and Hickey (1998) (general ecology of wet eucalypt forests and swamp forests). Details of the wet eucalypt forest communities by region are provided in the Forest Botany Manuals (Forest Practices Authority 2005). The Forest Botany Manuals also detail the relationships between the floristic community names as used in the above reports and the forest type names used in the Regional Forest Agreement.

1.3 Environment

Rainfall
The most important climatic requirements for the development of wet eucalypt forests are abundant and reliable rainfall and shelter from the worst desiccation of fire-promoting winds (Ashton 1981b). Wet sclerophyll forests occur throughout Tasmania where the average annual rainfall is in excess of 1000 mm, with at least 25 mm in the driest month (Forestry Commission, Tasmania 1987) and where low temperatures are not limiting to tree growth.

Temperature

Summers are warm to cool and winters are cool to cold. Summer maximum temperature averages 19 to 23°C, with winter minimum averages of 1 to 4°C. Frosts are common in the regions in which LWEF occurs, but they rarely penetrate the canopy of the forest. Young seedlings in clearfelled coupes are vulnerable to damage from frost heave on more exposed sites. Snow may fall occasionally.
Peak summer temperatures of about 40°C occur when slow-moving high pressure systems direct hot dry air from inland Australia over Tasmania. These are also periods of extreme fire danger.

Topography
Lowland wet eucalypt forests characteristically occur on slopes. Where rainfall is limiting LWEF are restricted to steep south-east facing slopes. In higher rainfall areas, the flats and gullies tend to be dominated by rainforest or swamp forest and LWEF dominates the slopes and ridges. The local distribution of rainforest, wet eucalypt forest and dry sclerophyll forest is also strongly influenced by fire history (Gilbert 1959, Jackson 1968).

Geology and Soils
Wet eucalypt forests occur on a wide variety of soils and rock types in Tasmania. Wet sclerophyll soils are usually acid, with a pH range of 4 to 6. The effect of soil in determining the distribution of species and communities is complex and may depend on both physical and chemical soil properties as well as, often overwhelmingly, the effects of climate or fire history. Attiwill and Leeper (1987) give some examples of the effects of soil fertility on the distribution of eucalypt species in mainland Australia.

1.4 Ecology

Litterfall
The litterfall in wet forests is an important contributor to soil fertility. It is also an important contributor to the flammability of LWEF. The litterfall of wet sclerophyll forests is relatively high by world standards in relation to climate (Bray and Gorham 1964). Litterfall in wet eucalypt forests has been measured at 4 to 6 tonnes/ha/year in southern Tasmania (Turnbull and Madden 1983). Rates of litter decomposition are highly variable. The weight of litter on the forest floor in mature *E. regnans* forest at Wallaby Creek in central Victoria amounted to 22 tonnes/ha, of which the leaf litter component was little more than the current years fall (Ashton and Attiwill 1994). Frankcombe (1966) has recorded accumulated fibrous and amorphous humus in amounts up to 160 tonnes/ha on the forest floor in *E. regnans* in the Florentine Valley where cooler temperatures allow the build up of high levels of forest litter. Litterfall in wet sclerophyll forests has a higher concentration of nitrogen and phosphorous than in dry sclerophyll forest due, at least partly, to the contribution from leaves of mesophytic understorey trees such as *Pomaderris, Olearia* and *Acacia* (Attiwill and Leeper 1987). Ashton (1976b) has recorded very high contributions of calcium from *Pomaderris aspera* leaves in wet sclerophyll forest in Victoria and has also drawn attention (Ashton 1987) to the same species for its effect in increasing soil pH.

Fire and soils; the ash-bed effect
The effects of wildfire on forest soils are reviewed by Attiwill and Leeper (1987). Temperatures up to 600°C can be achieved in the top centimetre of soil and the resultant ash is rich in nutrients such as calcium, magnesium and potassium. This can result in increased growth of eucalypt regeneration in wet forests (e.g. Jacobs 1955, Gilbert 1959, Hatch 1960, Attiwill 1962, Pryor 1963, Lockett and Candy 1984; Neyland *et al.* 2009). For example, Hatch (1960) recorded 28-year-old Karri regrowth on ash-bed with a height of 115 feet and a girth of 53 inches, whereas regrowth of the same age, not growing on ash-bed, was only 50 feet high with a girth of only 14 inches. Lockett (1998) found that the ash-bed effect was relatively short-lived and predicted that burning would only shorten rotation lengths by a maximum of five years.

Although losses of nutrients to the atmosphere occur during a fire, as both volatile and particulate matter (Harwood and Jackson 1975), the incremental effect of any one fire on the productivity of a site is likely to be small given the long history of fire in these forests. This was shown to be the case for a burn in the southern forests where it was concluded that nutrients lost in the area during a regeneration burn probably would be replaced by rainfall in 15 to 20 years (Ellis and Graley 1983). Similarly, Attiwill (1991) observed no response in growth of a young *E. regnans* forest, established after clearfelling and burning, following fertilisation with nitrogen and phosphorous, which he suggested supported the view that nutrients were not limiting. Adams and Attiwill (1988) also support the view that the loss of nutrients from a site through logging and burning will be replaced via rainfall well within the proposed rotation length.

Increased growth of trees established on ash-beds has also been attributed to microbiological changes. Soils may be completely sterilised to a depth of 2 cm or so by normal forest fires (Attiwill and Leeper 1987). This can destroy or suppress toxin-producing microflora such as the rhizosphere fungus *Cylindrocarpon* which has been found in *E. regnans* forest (Ashton and Willis, 1982). However, in tests conducted by Chambers and Attiwill (1994), which included the effects of a range of heating and partial sterilisation treatments on chemical, microbiological and physical properties of soil taken from a mature *E. regnans* forest, increased availability of nutrients, particularly nitrogen and phosphorous, were identified as the key component of the ash-bed growth response.

Wildfires

Infrequent wildfires are an essential and integral part of the environment of wet eucalypt forests. They have characteristic fire frequencies (Gilbert 1959, Jackson 1968, Mount 1979) ranging from once every 20 to 100 years for wet sclerophyll forests and 100 to 350 years for mixed forests. A combination of high rainfall and moderate to highly fertile soils allows the rapid accumulation of fuel while the presence of decorticating bark streamers, rough fibrous bark and other 'ladder fuels' can carry fires up into the eucalypt canopy under conditions of high winds, temperatures and low humidity (Mount 1970). Severe fire weather conditions, e.g. strong north-westerly winds and temperatures up to 40°C, occur when slow-moving high pressure systems direct hot dry air from inland Australia over Tasmania. Bad fire seasons, with more than twice the long term average area burnt, have occurred in seven summers since 1933, i.e. 1934, 1939, 1961, 1967, 1973, 1982 and 1995 (Ingles 1985, Penny Wells, pers. comm.).

The effects of fire on wet eucalypt forests are largely determined by the fire type and its residence time. Fires can be of three types: crown, surface or humus fires (Luke and McArthur 1978). Humus fires have a long residence time and can ringbark mature trees and destroy all the soil-stored seed (Cremer 1962; Mount 1970). Crown fires have a brief residence time. Ashton (1986) observed a flame residence time of only 10 to 12 seconds in eucalypt crowns burnt by the 1983 "Ash Wednesday" fire in Victoria. However, the after-burn of bark and stems was considerably longer. The timing is critical for survival of eucalypt seeds. Ashton (1986) demonstrated that 100% of *E. obliqua* seeds in capsules were killed when heated to 290°C for 80 seconds. Mount (1970) suggests that significant survival of eucalypt seed may result because the capsules are held below the leaf masses and the majority of the heat is swept upwards.

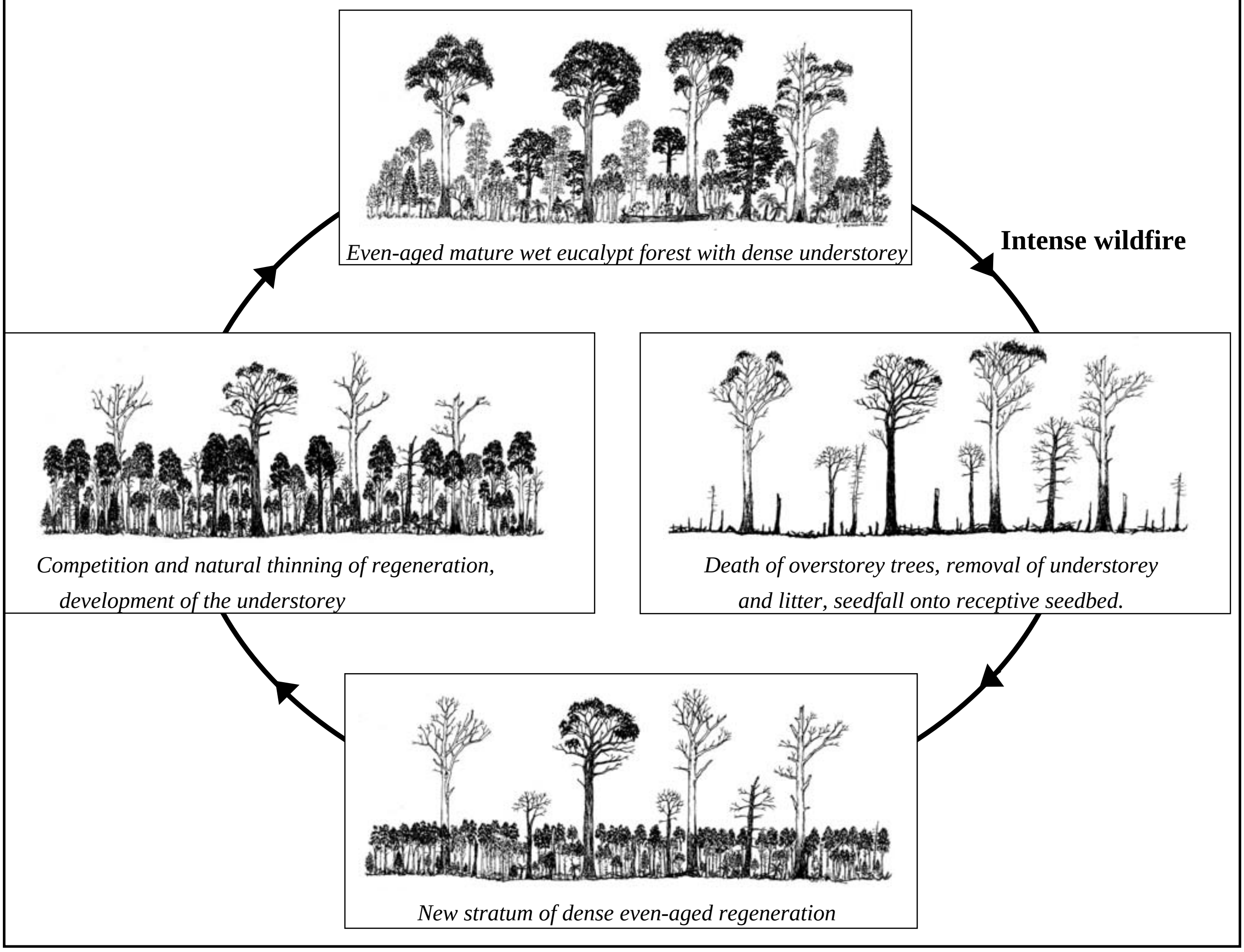
Regeneration of the eucalypts

Regeneration in wet eucalypt forests occurs only after severe disturbance such as fire. Fire, however, is not essential to seedling establishment, as removal of the understorey and many other physical effects of fire, can be achieved without fire (Gilbert 1959). For example regeneration of eucalypts is dense along roadsides which have been cleared to bare soil next to mature eucalypt forest, and regeneration will occur in logged areas when slash is not burnt. Only very rarely though, will individual tree-fall create enough disturbance and exposure of mineral soil to allow eucalypt regeneration (Gilbert 1959, Ellis 1985).

Early survival and growth of seedlings has been clearly demonstrated to be very much higher on seedbeds created either through the use of fire or through mechanical disturbance than on undisturbed litter (e.g. Gilbert 1959, Pryor 1960, 1963, Lockett and Candy 1984, Technical Bulletin 11). Neyland *et al.* (2009) also showed that more seedlings established on burnt ground than on disturbed ground all else being equal. King (1991) has shown that in LWEF, mechanical disturbance is significantly more expensive than slashburning, except on the smallest (<4 ha) coupes. Burning of the slash post-logging also has an advantage over mechanical disturbance in that the slash is removed by the fire. The very heavy slash loads that remain on-site following logging of LWEF would create an increased risk of the coupe being burnt in a subsequent fire, if they were not removed by the regeneration burn. As a result, mechanical disturbance is rarely used. Eucalypt seedlings thrive in the open conditions created by fires and can quickly outgrow competing species. Once established, eucalypts will form a canopy over rainforest or wet sclerophyll understoreys and can persist for about 350 years (Gilbert 1959).

In the low light conditions present beneath dense wet forest understoreys, eucalypt seedlings are incapable of persisting past the juvenile phase. The lack of success of eucalypt regeneration under conditions of low light can be partially related to the light compensation points (LCPs, i.e. the light intensity at which photosynthesis just balances respiration) of individual species. Ashton and Turner (1979) have shown a strong correlation between the LCPs of major wet eucalypt forest understorey species and their relative shade tolerance. Highly shade tolerant species such as sassafras (mixed forest understorey) and musk (wet sclerophyll understorey) have very low LCPs while adult *E. regnans* have a high LCP in comparison. Ashton and Turner (1979) also report that the light requirement of eucalypts such as *E. regnans* increases with age, which helps explain the lack of persistence of eucalypt juveniles germinating on the forest floor or in small canopy gaps. Only those germinating in heavily disturbed areas (eg. after fire) or in the open conditions of dry sclerophyll forests are able to persist to the adult stages. Low light intensities also increase the susceptibility of shade intolerant species to pathogens, insect attack and marsupial browsing. Under conditions of high light intensity, eucalypts usually have a remarkable ability to recover from such effects (Ashton 1981b, Ashton and Turner 1979). The natural regeneration pathway of wet eucalypt forest is illustrated in Figure 2.

Figure 2. The natural regeneration pathway of lowland wet eucalypt forest involves major and infrequent disturbances.



Regeneration of the understorey

The majority of wet sclerophyll vascular species can regenerate after fire either from soil-stored seed or vegetatively. Ashton (1981a) has recorded that dogwood species, wattle species, Christmas bush, musk and dolly bush all regenerate from soil-stored seed and noted that blanket bush and musk have lignotubers and can regenerate vegetatively. Howard (1981) found that there was very little soil storage of rainforest species seed. However Barker (1990) recorded eight vascular rainforest species which were able to regenerate vegetatively after fire. Hickey (1994) found that most common vascular rainforest species were present in 20 to 30-year-old eucalypt regrowth forest which had re-established after wildfire in mature mixed forest. However, rainforest species were often inconspicuous amongst a dense layer of sclerophyllous shrubs.

Recent studies (Mueck and Peacock 1992, Ough and Ross 1992, Hickey 1994, Peacock and Duncan 1995) have shown that young silvicultural regeneration following clearfelling is distinct from similar aged regeneration following wildfire in that there is a reduction in the numbers of tree ferns and epiphytic ferns (which rely on the tree ferns as hosts).

Seed storage

There is virtually no soil storage of eucalypt seed (Gilbert 1959, Cunningham 1960a, Cremer 1965a): the storage of eucalypt seed is in the capsules in the canopy. Persistence of capsules for three or more years usually ensures that at least the crop of one good flowering season is present (Ashton 1981a, b). Heat-scorch from fire causes the hard woody capsules to open and an accelerated seed-shed is induced (Cremer 1965a, Christensen 1971). Hot fires therefore result mainly in even-aged regeneration of eucalypts (from capsule-shed seed) and understorey species (from soil-stored seed) (Ashton 1981a). Additional regeneration of understorey species will subsequently occur from wind and bird dispersed seed.

Successful regeneration establishment and subsequent development

After a fire in wet eucalypt forests the survival of eucalypt seedlings is assured due to the favourable conditions which prevail. Gilbert (1959) describes such conditions as including:

- the removal of the dense understorey and resultant increase in forest floor light intensities,
- the removal of the litter layer,
- an exposed mineral soil and high nutrient status from the ash,
- heavy seedfall from large numbers of capsules which survive on parent trees,
- the reduction in the number of insects which harvest seed, and
- good rains associated with cold fronts which often follow extreme fire weather.

Under these conditions eucalypt seedling regeneration is extremely dense. Density counts of seedlings in the cotyledonary stage immediately after fire range enormously with Jackson (1968) estimating between 100 000 and 1 000 000 seedlings/ha, and Ashton (1976a) reporting counts for *E. regnans* between 494 000 and 2 470 000 seedlings/ha. Such densities result in heavy competition and, as a result, thinning of eucalypts with age is very rapid (Ashton 1981b). This is most dramatic during the first few decades, until at about 40 years numbers have declined to fewer than 400 stems/ha (Ashton 1976a). From 40 years onward stand density declines more slowly (Ashton 1976a), and by 300 years after fire there may be as few as two eucalypts/ha (Jackson 1968). Most of the height is attained by individual eucalypts during their first 100 to 140 years of growth (Ashton 1976a). After this time little height is gained but the trees increase greatly in girth until around 300 to 350 years, after which they senesce and die (Jackson 1968).

Suppressive effects of retained overstorey on regeneration

The suppression of regrowth by retained trees has been demonstrated for a number of eucalypt species (e.g. Rotheram 1983, Kellas *et al.* 1987, Dignan *et al*. 1998). Competition for moisture appears to be the major factor; suppression of growth is greater at high retained basal areas and on sites with low rainfall. An example of this effect is given in Figures 3 and 4. Significant suppression of regeneration can be expected where the basal area of retained trees exceeds 12 m^2 per hectare on dry sites (<1000 mm per year) or 16 m^2 per hectare on wet sites (> 1000 mm per year) (Battaglia and Wilson 1990). On dry sites, the zone of suppression may occur to a distance of up to six times the crown radius of the retained tree (Incoll 1979). Rotheram (1983) estimated that each 5% crown cover of retained trees would reduce the growth of regeneration by 10%. Kellas *et al.* (1987) also showed that it was the total competition (i.e. from both the retained overstorey and from the surrounding regrowth) that controlled the basal area increment of the regrowth stems and also, importantly, that the trees retained the capacity to respond to release from competition for at least 25 years.

Figure 3. Height of *E. regnans* seedlings at age 3 years under varying levels of *E. regnans* overwood retained after harvesting.

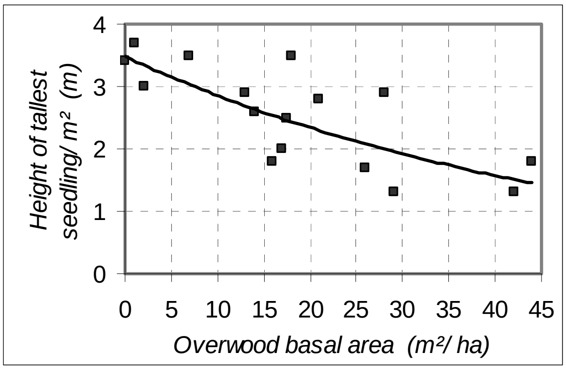
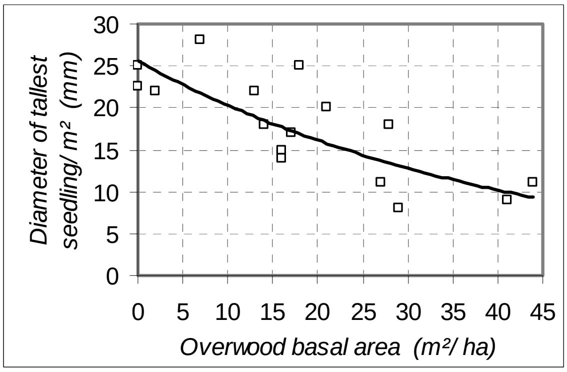


Figure 4. Diameter of *E. regnans* seedlings at age 3 years under varying levels of *E. regnans* overwood retained after harvesting.



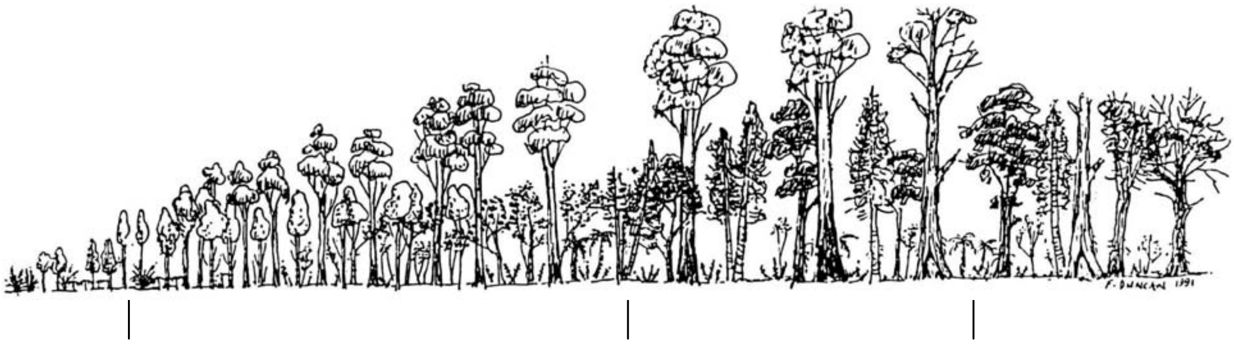
from Dignan *et al.* 1998

Promotion of fire by eucalypts

Eucalypts possess a number of regeneration strategies and physical characteristics which not only aid post-fire recovery, but also promote the incidence of fire. Epicormic buds protected beneath the bark in the cambium, normally lie dormant but exhibit prolific growth after fire. Most eucalypts can also regenerate vegetatively by suckering from lignotubers which are protected beneath surface soil at the base of the tree, although some, including *E. regnans* and *E. delegatensis* do not develop lignotubers (Jacobs 1955). Some prominent wet sclerophyll understorey species, such as blanket bush and musk also regenerate from lignotubers (Ashton 1981a). Fire-promoting features of eucalypts include decorticating bark, which can develop into fire brands encouraging spot fires up to several kilometres ahead of the fire front; highly flammable aromatic oil contents of the foliage and twigs; heavy litter fall; and open crowns and fibrous bark which encourage crown fire development (Mount 1970, Ashton 1981a, Jackson 1981). These pyrogenic features sustain wet eucalypt forest communities in environments which, in the absence of fire, would be climatically most suited to rainforest development.

Succession in lowland wet eucalypt forest
A general model of the succession from non-forest vegetation - wet sclerophyll forest - mixed forest - rainforest has been described by Jackson (1968). The model is summarised in Figure 5 which indicates a likely succession on a fertile site.

Figure 5. The succession of lowland wet eucalypt forest over time.



wet sclerophyll forest | mixed forest | rainforest

Years… 25 **150** **350**

From left to right shows the changing stand structure with increasing time since a stand replacing wildfire.

Due to the many factors controlling fire intensity (e.g. accumulated fuel, interval since last fire, fuel moisture content, weather), forests can be variously affected by a single fire event. Cool surface fires may only remove understorey vegetation leaving the eucalypt canopy virtually intact. Hot crown fires on the other hand, can raze a whole forest. As a result, in any one area, many combinations of understorey age, structure and floristics can occur, which are associated with the combinations and frequencies of crown, surface, and humus fires (Cremer 1962, Ashton 1981a, b).

Repetitive burning of a site can have dire consequences for wet eucalypt forest communities. A second fire prior to newly regenerated seedlings reaching sexual maturity may entirely eliminate a species from an area due to a lack of propagules (Jackson 1981). However, even where wildfires have been frequent, such as in wet eucalypt forests of the Esperance and Plenty valleys, a low stocking of eucalypts persisted although extensive areas of the original forest communities were replaced by bracken (A.B. Mount pers. comm.).

Mature wet eucalypt forests are usually multi-aged. (Turner *et al.* 2009). This can occur when surface fires which destroy the shrub understorey are not intense enough to kill all the eucalypt dominants, but are intense enough to promote eucalypt regeneration. In very severe fires, where even the humus layers are burnt above the mineral soil, the entire forest stand may be killed. Colonising species other than eucalypts therefore rely on wind or bird dispersal for establishment to occur. Eucalypt regrowth is determined by the proximity of a seed source. Cremer (1965a) estimated that seed sources (including seed from fire-killed crowns) need to be within 200 m for eucalypts to be replaced as the dominant life form. After less intense fires the first communities to develop are derived from soil-borne seeds, from fire-resistant capsules, from rapidly dispersed propagules and from vegetative regeneration (Ashton 1981b). In the earliest stage after a severe burn mosses and liverworts are prominent colonisers of bare ground, but these are overtopped by herbs, ferns or woody regrowth within one to two years after fire (Cremer and Mount 1965).

In areas that are burnt frequently, broad-leaved shrub regrowth is restricted and fernlands develop rapidly. On the drier ridges or on well drained flats bracken is the dominant fern, while batswing fern and ruddy ground fern are favoured in wetter gullies and in areas of high rainfall (Jackson 1981).

In the absence of rainforest species wet sclerophyll understoreys develop beneath the maturing eucalypt regrowth. Rainforest species may be expected to become prominent in a wet sclerophyll understorey within 100 years, if they are present in the vicinity (Ashton 1981b). If there are no fires in the succeeding century rainforest will completely replace the wet sclerophyll understorey. Overtopping eucalypts gradually diminish throughout the next 200 years unless the forest is subject to further fire. In the highest rainfall areas fire frequency is lowest but the drier the region the more likely the successional sequence will be interrupted by fire. In areas of relatively high fire frequency mixed forests may never develop, except perhaps in fire protected gullies, and consequently an array of wet sclerophyll communities will dominate, with floristic differences reflecting fire history, moisture and nutrient availability, soil development or altitude.

Succession proceeds along different paths if rainforest species do not occur in the vicinity of burnt stands of wet eucalypt forest. Wet sclerophyll understorey species replace each other according to individual species light tolerances, competitive behaviour and life span. An understorey of dolly bush will survive for only 25 to 30 years beneath a canopy of *Eucalyptus regnans* (Ashton 1981b) after which a more luxuriant shrub stratum dominated by dogwood and musk becomes prominent. Fire-regenerated species such as silver wattle reach senescence between 50 and 60 years after fire, after which time they disappear from the wet sclerophyll understorey until the next fire causes germination of soil-stored seed.

2. Regeneration and establishment

The successful establishment of eucalypt seedlings requires receptive seedbed, an adequate seed supply, suitable environmental conditions and effective mammal browsing control.

2.1 Seedbed

Receptive seedbed

A receptive seedbed is one which has had the litter layer removed either mechanically or by fire, exposing mineral soil, and from which the competing understorey vegetation has been removed, allowing sufficient light to reach the forest floor. Without sufficient light the early growth rates are greatly reduced and mortality is high. Seeds germinating on a duff or litter layer are susceptible both to drought death in the summer and fungal attack in the winter.

Germination

The natural seedfall in most LWEF eucalypt species peaks in late summer and autumn. Seeds falling onto receptive seedbeds at this time have a greater chance of being incorporated in the top layer of the soil before the winter rains settle and harden the surface. It has been shown that field germination is substantially improved if the seed has a shallow covering of loose soil (Cremer 1965b). Where the seed is covered by soil it is protected to some extent from natural predators such as ants (Stoneman and Dell 1993). Water infiltration and aeration in the disturbed soil can be greater than in undisturbed soil and contact between the seed and the soil can be improved (Kozlowski and Gunn 1972).

2.2 Seed

Seed supply

There is a large natural variation in the annual rate of seed production in eucalypts (e.g., Gilbert 1958, Cunningham 1960b, van Loon 1966, Ashton 1975, Neyland *et al.* 2003). It is thought likely that a large seed crop one year uses a lot of the tree's food reserves, as two successive heavy seed crops are rarely observed (Ashton 1975). It is also true that some stands can produce a heavy seed crop while nearby stands of the same species produce very light seed crops (Loyn 1981). In even aged regrowth forests (30 to 80 years old), smaller crown size, higher stocking levels and rapid ejection of mature capsules can tend to inhibit heavy seed crops (Harrison *et al.* 1990).

Seedfall

The cycle of flower bud initiation through to seedfall is described in detail in Technical Bulletin No. 1. Seedfall is triggered by the drying out and opening of the capsule valves as a result of the formation of an abscission layer at the base of the stalk of the capsule (Florence 1996). As seed is shed when the capsule dries out, the greater part of a seed crop is normally shed at a seasonally dry time of the year (Florence 1996). In *E. regnans* in most years, the capsules release most of their seed in the autumn of the year after the capsules mature (i.e. approximately two years after flowering (Cunningham 1957, 1960b, Gilbert 1958, Ashton 1975, Harrison *et al*. 1990). Cremer (1965a) found that seed shed of *E. regnans* was evenly distributed through the year in two wet years, but was concentrated in autumn during four years when summers were hot and dry. Heavy seed shed often occurs as a result of crown scorch or death of branches following fire or drought. Once shed, eucalypt seed does not remain viable in the litter layers or soil for longer than 12 to 18 months (Cremer *et al*. 1978). For successful regeneration to occur in LWEF, it is therefore important that the seed is sown onto receptive seedbed.

Timing of sowing

The competing vegetation in LWEF develops more quickly than in drier forests so early establishment of the regeneration is more important. Seed should be sown immediately following the regeneration burn. Seed that is sown too late in the autumn is not likely to germinate until the following spring. If sowing is delayed for too long on wet sites much of the seedbed may be overgrown by ground-hugging plants such as mosses and liverworts. This prevents the seed from establishing contact with the soil from which it must be able to obtain moisture to germinate and grow. Cremer and Mount (1965) reported that sowing *E. regnans* sites more than one year after a fire was a dismal failure.

2.3 Factors affecting survival

Light

Seed may germinate under dense canopy or heavy slash but seedlings will fail to thrive and quickly die. At least 10 to 30% of full sunlight is required for the growth of light-demanding (shade intolerant) species such as eucalypts. An undisturbed eucalypt overstorey normally allows about 30 to 40% of full sunlight to penetrate, however the dense understorey of LWEF reduces the final light intensity at ground level to 4 to 8% of full light (Ashton and Willis 1982). Ashton and Turner (1979) found that the light requirements of *E. regnans* increases as trees age, which helps explain the lack of persistence of juveniles which germinate on the forest floor or in small canopy gaps.

Frost, heat and drought

Many early seedling losses are due to frost heave, especially on very friable soils including ashbeds. Sowing as early as possible allows the seedlings time to establish adequately such that losses due to frost heave are reduced.

High soil surface temperatures can be a significant cause of seedling death in summer, although it is difficult to distinguish between the effects of heat and drought (Florence (1996). Cunningham (1960a) found that surface temperatures within cutover and burnt *E. regnans* forests reached up to 66°C. Recent germinants are more susceptible to heat stress than older seedlings, which is another reason why autumn sowing is preferred to spring sowing.

Drought during the early establishment phase may cause mortality, especially on exposed northerly aspects. Spring sown seedlings are more susceptible to summer drought than autumn sown seedlings, as they have had less time to establish. Spring sowings should commence as early as late July and should be completed by mid-September.

Fungal attack
Fungal attack of very young seedlings is a common cause of seedling loss, especially in winter and on sites where the litter and duff layers have not been removed. Fungal attack may be reduced on seed beds prepared by a hot fire (Florence 1996). Trials designed to demonstrate the impact of fungal attack on seedling establishment were inconclusive, but showed that a wide range of fungal isolates were associated with discolouration and subsequent death of *E. regnans* seedlings (Lacey 1995).

Browsing
Browsing by native animals and by insects is a major cause of early seedling loss. Insects may browse cotyledons or nip off hypocotyls. Seedlings which are severely damaged at the cotyledonary stage are unlikely to survive. Browsing of cotyledons by native animals is a major factor in the reduction of tree percent (the number of trees established for each 100 seeds sown).

Cremer and Mount (1965) suggested that selective browsing can alter the composition of the regenerating forest. They reported that stinkwood has a competitive advantage over dogwood and wattle species due to its relative unpalatability. Hickey (1982) measured very selective browsing of seedlings of some rainforest tree species. A number of authors have reported severe marsupial browsing damage to blackwood seedlings in swamp forests (R. Mesibov pers. comm. 1980, Anon 1982, Hickey and Felton 1991).

Wilkinson and Neilsen (1995) found that young seedlings of *E. nitens* and *E. regnans* were able to tolerate moderate levels of browsing (up to half the crown removed) without any long term detrimental effect to either survival or growth. Tolerance to browsing by native animals increases as the seedling increases in height and damage by wallabies once the seedling is over 1 m high is generally tolerable. Damage by possums to gum species can continue to be a problem.

2.4 Summary of regeneration and establishment

Successful regeneration requires:

- extensive seedbed preparation by fire or mechanical disturbance,
- adequate supply of high quality seed,
- high light levels,
- reduced levels of overstorey competition,
- freedom from heavy frosts and drought, and
- freedom from excessive damage by insects and browsing animals.

3. Stand Health

Monitoring

Formal monitoring for beetle or other insect attack is currently undertaken only in plantations. There is no formal monitoring of silvicultural regeneration. However informal monitoring of stands should be part of normal District practice. Unthrifty regeneration or excessive mortality from unknown causes needs investigation and should be brought to the attention of the forest pathologist.

Insect attack

The most damaging insect pests of Tasmanian commercial eucalypts are leaf beetles (Coleoptera: Chrysomelidae) (Elliott and deLittle 1984). Chrysomelid leaf beetle attack can severely reduce the growth of eucalypt regeneration and plantation trees (Elek 1997). Leaf beetles and their larvae feed on the leaves of a number of eucalypt species (Greaves 1966). Kile (1974) has described the defoliation of eucalypt regrowth forests by *Chrysophtharta bimaculata*. *C. bimaculata* occurs naturally on many eucalypt species including *E. regnans, E. obliqua* and *E. globulus*, but appears to have definite host preferences (Kile 1974, de Little and Madden 1975). Other insect pests which can cause significant damage to eucalypts include *Mnesampela privata* (autumn gum moth) and *Uraba lugens* (gumleaf skeletoniser) (Elliott and deLittle 1984).

Dieback

Regrowth dieback

Regrowth dieback is the progressive death of the primary crown coupled with epicormic shoot production of variable longevity (Table 3). It was identified in the southern forests, on the Forestier Peninsula, Wielangta, Bass District and at Castra (Podger *et al*. 1980). Regrowth dieback predominantly affects dominant and co-dominant trees of *E. regnans* and *E. obliqua* in regrowth forests older than 30 to 40 years (Wardlaw 1989). Despite a large research effort, the exact cause of regrowth dieback remains unknown (Podger *et al*. 1980). There is circumstantial evidence that links regrowth dieback with drought events (West 1979, Podger *et al*. 1980, Wardlaw 1989), as regrowth dieback can appear after droughts of short duration but of severe intensity, or after longer dry spells.

Gully dieback

Dieback events in the north-east in the late 1960s were also believed to be associated with a drought event, when over a five month period only 47 mm of rain fell on an area centred on Mathinna and there was extensive death of *E. obliqua* in the gullies (Palzer 1981).

Calder dieback

In the north-west in the early 1970s there was extensive defoliation of *E. obliqua* in several valley systems around Calder (hence Calder dieback). The worst affected areas were steep north-south running valleys and the disease was believed to be caused by the leaf spot fungi *Aulographina eucalypti*, which was encouraged by the occurrence of persistent valley fogs (Palzer 1978).

Table 3. Comparative characteristics of three eucalypt diebacks in *E. obliqua* forests in Tasmania (after Podger *et al.* 1980).

Name	*Age of trees affected*	*Pattern of occurrence*	*Topographic relationship*	*Development in time*	*Effects on regeneration*	*Probable cause*	*Source*
Regrowth dieback	30-100	Extensive, diffusely scattered in lowland forests	Independent	Persistent since early 1960s, not observed recently	None	Unknown	Podger *et al.* 1980
Calder dieback	All ages	Patchlike	Valleys to higher slopes	Episodic	Unknown	Complex of leaf spot fungi, insect defoliation, drought	Palzer 1978
Gully dieback	All ages	Patchlike	Valleys and lower slopes	Episodic	Healthy regeneration beneath killed overstorey	Drought with insect defoliation, with *Armillaria* secondary	Palzer 1981

Wood decay

Wood decay has been identified as a major concern in the management of *E. obliqua* and *E. regnans* silvicultural regeneration by Wardlaw *et al*. 1997. They found that up to 15% of the potentially merchantable sawlog volume at rotation was downgraded because of excessive decay in the butt log (0–6 m) and up to 30% in the head log (6–12 m) sections. This equates to a net value-adding loss to the Tasmanian economy of up to $250/ha (Wardlaw *et al*. 1997). On highly productive sites currently suitable for commercial thinning, appropriate selection of the retained trees could reduce by 20 to 30% the losses due to downgrading of sawlogs because of stem decay in the final crop.

Wardlaw *et al.* 1997 found that the levels of decay were somewhat higher in *E. obliqua* regeneration than in *E. regnans*. They also found that low stocking and the corresponding increase in average abundance and size of branches, appears to be associated with an increased level of decay. Trees which retain on their bole (i.e. below the actively growing crown) more than five branch stubs of between 10 and 30 mm diameter are likely to have high levels of decay (Wardlaw *et al*. 1997). For a given area of regrowth, selection of such trees for removal will improve the overall quality of the stand.

In order to minimise the levels of decay, to provide sufficient stems to allow the selection and removal of decay prone stems, and to ensure that rapid clear bole extension is achieved, it is essential that the initial stocking of the stand is at least 2500 stems/ha (Wardlaw *et al*. 1997).

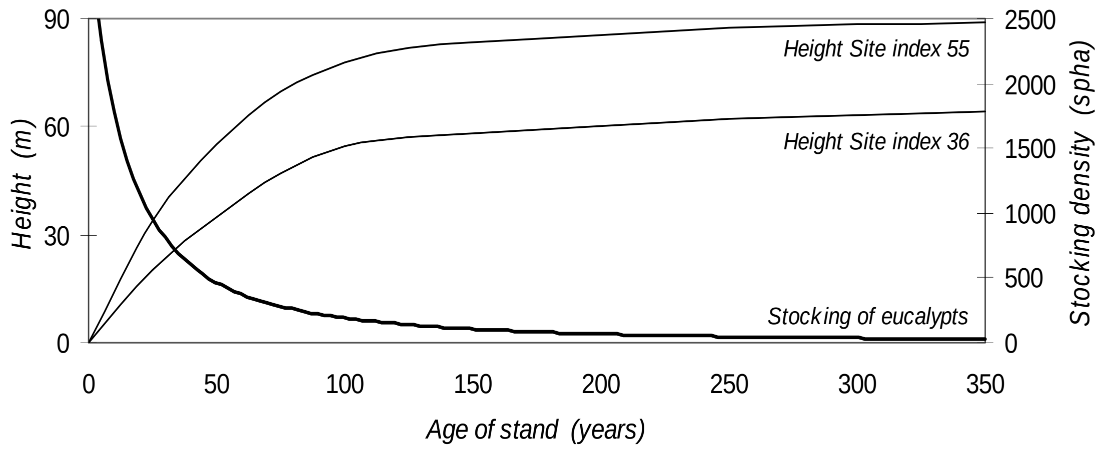
In less dense stands, clear bole extension is slower, the likely incidence of stem decay is higher and the stand will not be suitable for early age spacing as the stocking will be insufficient to allow the removal of the decay prone stems (or even the selection of crop trees).

4. Growth and Yield

4.1 Stocking and growth

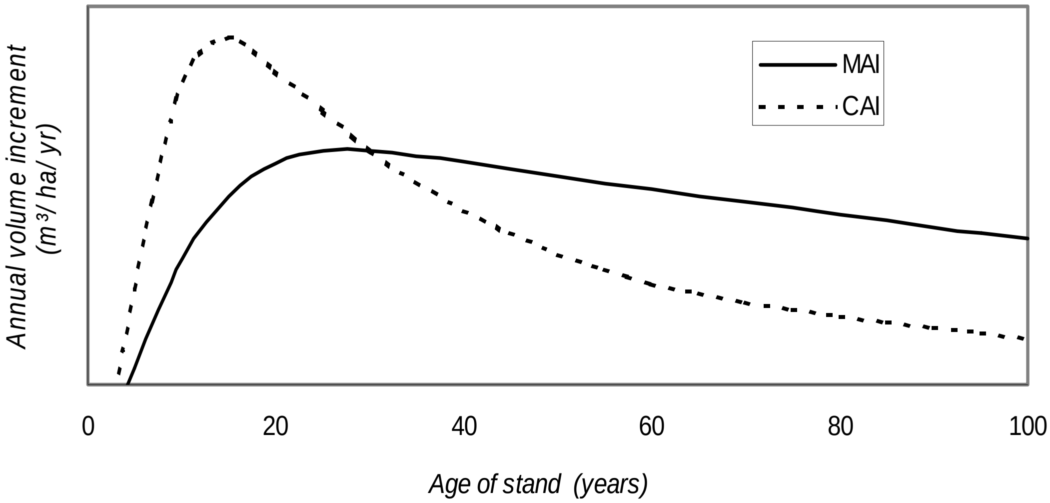
The stocking of seedlings following natural regeneration is highly variable but can be as high as 2.5 million seedlings per hectare (Ashton 1976). Silvicultural sowings normally produce stocking levels of 2000 to 12 000 seedlings per hectare. Early competition is intense, particularly during the first ten years when the root systems of eucalypts compete directly with other species such as *Pomaderris* (Ashton 1976). On highly productive sites the initial height growth of species such as *E. regnans* is very rapid. *Eucalyptus regnans* may reach about half its final height by age 25 to 35 years (Jackson 1968, Ashton 1976). Stocking levels fall rapidly to about 400 to 500 stems per hectare by age 40 years (Figure 6). The maximum height of about 90 m is approached by about age 120 years. Beyond this age there is little increase in height, but diameter growth and therefore volume production continues, up to the age of about 300 years (Jackson 1968, Ashton 1976). During the overmature stage (300 years+) the crown suffers increasing dieback and the total height reduces as the crown is progressively replaced by epicormic branches from the upper portion of the living stem.

Figure 6. Stocking and height growth of eucalypts over time. (from Gilbert 1959 and Jackson 1968).



Annual volume production increases rapidly for the first twenty years of the life of a stand (Figure 7). Once the site is fully occupied, total volume increment slows due to the increasing senescence and mortality of suppressed trees. During this period, increment on the dominant trees in the stand is maintained even though total stand increment may slowly decline.

Figure 7. Change with age in mean annual increment (MAI) and current annual increment (CAI) for a moderately productive stand of *E. obliqua*. (from West and Mattay, 1993).



Site index (SI) is used as a relative measure of the productivity of a site. For eucalypt forests it is defined as the mean dominant height (MDH) of a stand at age 50 years. Mean dominant height is the mean of the heights of the dominant tree on each 1/30th of a hectare (Forestry Commission 1964). Mean dominant height is used to determine site index because it is relatively insensitive to stocking (Adrian Goodwin pers comm).

In Tasmania, forest height and stocking information is derived from aerial photographs and recorded on forest photo-interpretation (PI) maps (as a GIS coverage). These maps may also record other details such as age and origin of the stand and the height class of the previous forest. The PI types are summarised in Table 4. It should be noted that PI type does not equate to site index since no allowance is made for the age of the mature forest.

Table 4. PI type classes definitions for mature and regrowth stands.

Mature Eucalypt (E)

PI class	*Height (m)*	*Density*	*% crown classes*
E1*	> 76	a	70 – 100
E1	55 – 76	b	40 – 70
E2	41 – 55	c	20 – 40
E+3	34 – 41	d	5 – 20
E-3	27 – 34	f	<5
E4	15 – 27		
E5	< 15		

Eucalypt Regrowth (ER)

PI class	*Height (m)*	*Density*	*% crown classes*
ER6	> 50	a	90 – 100
ER5	44 – 50	b	70 – 90
ER4	37 – 44	c	50 – 70
ER3	27 – 37	d	10 – 50
ER2	15 – 27	f	1 – 10
ER1	<15		

4.2 Productivity and yield

The area of eucalypt forest available for harvesting on State forest in Tasmania is around 500 000 ha (Forestry Tasmania 2007). The estimated standing volume of sawlog and veneer in that forest is about 7 million m^3. The mean annual increment (MAI) of wood (all classes) in the more productive regrowth eucalypt forests is about 4 m^3/ha.

The total merchantable volume of existing stands is very variable and ranges from 50 to over 1000 tonnes per hectare, depending on site quality, age and stocking. Forests carrying less than 50 tonnes per hectare would generally be regarded as non-commercial.

Yield by volume from a typical coupe

Average yields from clearfelled virgin stands are about 50 m^3/ha of sawlog and veneer, and about 250 t/ha of pulpwood. Yields can be higher than this in exceptional stands. A seven-year-old *E. regnans* forest which regenerated after the Ash Wednesday fires in Victoria in 1983 had a mean entire stem volume increment of 50 m^3/ha/year (Attiwill 1992). The ratio of sawlog to pulpwood is higher in the lowland wet eucalypt forests (up to 1:1) than in the drier forest types (1:30 is typical of much of the east coast forests).

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