The Effects of Fire Intensity on the Regeneration of Mixed Forest Tree Species in the Clear Hill/Mount Wedge Area

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Abstract

Surveys of the regeneration of eucalypts, rainforest tree species and Acacia *species have been carried out in clearfelled mixed forest coupes in the Clear Hill/Mount Wedge area, five to eight years after regeneration burns. For most species, including eucalypts, stocking rates were not significantly different between mudstone and quartzite. Eucalypt regeneration was taller and more vigorous on mudstone sites. Eucalypts appear to regenerate to adequate stocking levels on many sites with low intensity burns, though the proportion of understocked areas requiring remedial treatment is greater than on comparable sites which have had hotter burns. On sites with high fire intensities, eucalypt stocking rates are appropriate for future pulpwood production but thinning may be required if sawlog production is the main priority. Rainforest and* Acacia *species regenerate more successfully in the absence of fire or following low intensity burns than they do following high intensity burns. The regeneration of understoreys containing the range of mixed forest tree species may be desirable for ecological, aesthetic and commercial reasons.*

Introduction

Little research has been published on the regeneration of rainforest species after clearfelling of mixed forest (forest with eucalypt dominants over a rainforest understorey, Gilbert 1959). Forestry research has focussed on the regeneration of eucalypts following logging whereas ecological research has focussed on regeneration following wildfire. Cremer and Mount (1965) described early succession after logging and burning in the Florentine Valley but their discussion does not consider the effects of different fire intensities. They suggest that in the first 10 years after fire, the vegetation will progress from pioneer bryophytes and low herbs, to fire weeds (mainly *Senecio linearifolius*) and ferns, and then to woody plants typical of wet sclerophyll forest. They found very little regeneration of the rainforest species myrtle (*Nothofagus cunninghamii*) and sassafras (*Atherosperma moschatum*). Hill and Read (1984) and Barker (1991) showed regeneration favoured sclerophyll species following wildfire in mixed forest in western Tasmania.

The regeneration ecologies of rainforest and sclerophyll tree species are different. The rainforest tree species myrtle, sassafras and leatherwood (*Eucryphia lucida*) appear to show continuous regeneration under a canopy (Read and Hill 1988; Neyland and Hickey 1990). This regeneration may be from seed, but sassafras frequently coppices, and myrtle and leatherwood are also known to coppice (e.g. Barker 1991). Eucalypts and *Acacia* are dominant and subdominant sclerophyll tree species of mixed forest in the Clear Hill/Mount Wedge area. *Eucalyptus regnans* only regenerates from seed and cannot survive under a canopy, and hence is dependent on major disturbance such as wildfire for regeneration (Ashton 1981). Other eucalypts in the area, *E. delegatensis,* *E. obliqua* and *E. viminalis*, also require disturbance for regeneration but may regrow from coppice as well as seed. Blackwood (*Acacia melanoxylon*) regenerates from seed which remains viable in the soil for many decades (Hickey 1982) and germinates after disturbance. Silver wattle (*A. dealbata*) appears to have a similar regeneration ecology (Gilbert 1959; Cunningham and Cremer 1965).

Re-establishment of mixed forest after severe disturbance such as fire or logging requires the regeneration of both eucalypt and rainforest species. If a species does not regenerate from seed or coppice soon after the fire, then it must establish under a developing wet sclerophyll canopy. In the Clear Hill/Mount Wedge area, this canopy is dominated by dogwood (*Pomaderris apetala*), musk (*Olearia argophylla*), blanket bush (*Bedfordia salicina*), *Acacia* species and eucalypt regeneration. Rainforest species are known to be relatively shade tolerant (Read 1985) and sassafras is likely to survive under a canopy, although myrtle may require a break in the canopy for growth (Read and Hill 1988). However, the rainforest species can only establish under the wet sclerophyll canopy if propagules are available, either from good dispersal or long-term viability of soil-stored seed.

In the absence of further disturbance, wet sclerophyll forest may succeed to mixed forest if rainforest species increasingly dominate the understorey. Further succession to pure rainforest may occur if the eucalypts become moribund and die (at an age of about 400 years), and the density of the rainforest canopy has precluded successful establishment of shade intolerant seedlings of eucalypts and other sclerophyll species (Gilbert 1959; Jackson 1965, 1968).

The effects of clearfelling followed by regeneration burning may be significantly different from the effects of wildfire on regeneration of rainforest tree species. Wildfire leaves many more dead trees, logs on the ground and residual rootstocks. This may reduce soil erosion and provide sheltered sites for seedling regeneration. Wildfire may be more patchy, which will facilitate regeneration from coppice on lightly burnt sites. Trees surviving wildfire may provide an additional seed source, or the only seed source if soil-stored seed is destroyed by fire. Myrtle and leatherwood have poor soil storage of seed, are poorly dispersed, and mostly regenerate from seed from standing trees (Hickey 1982; Neyland and Hickey 1990). They therefore will be disadvantaged by clearfelling (i.e. complete removal of trees) followed by burning. The gap between logging and burning may be too long for the soil-stored seeds of some mixed forest species (e.g. sassafras) to remain viable (Hickey *et al.* 1982). However, the longevity of soil-stored *Acacia* seeds is well documented (Gilbert 1959; Cunningham and Cremer 1965; Forestry Commission 1991a).

This paper examines the regeneration of the tree species most typical of mixed forest (eucalypts, myrtle, sassafras, leatherwood, celery-top pine [*Phyllocladus aspleniifolius*], blackwood and silver wattle) in coupes in the Clear Hill/Mount Wedge area. The coupes were surveyed five to eight years after regeneration burns following logging of mixed forest. This paper is only concerned with the short-term regeneration of these tree species, since some may enter the forest at a later stage. Comparisons are made between regeneration of these species on different substrates and after different intensities of regeneration burn.

Methods

The study area

The Clear Hill/Mount Wedge area is located to the east of the Gordon impoundment (Fig. 1) in the perhumid cold climatic zone (Gentilli 1972). The bedrock types in this area are quartzites, conglomerates and Cambrian mudstones (Geological Survey of Tasmania, Huntley and Pedder 1:50 000 maps). Only quartzites and mudstones occur in the study

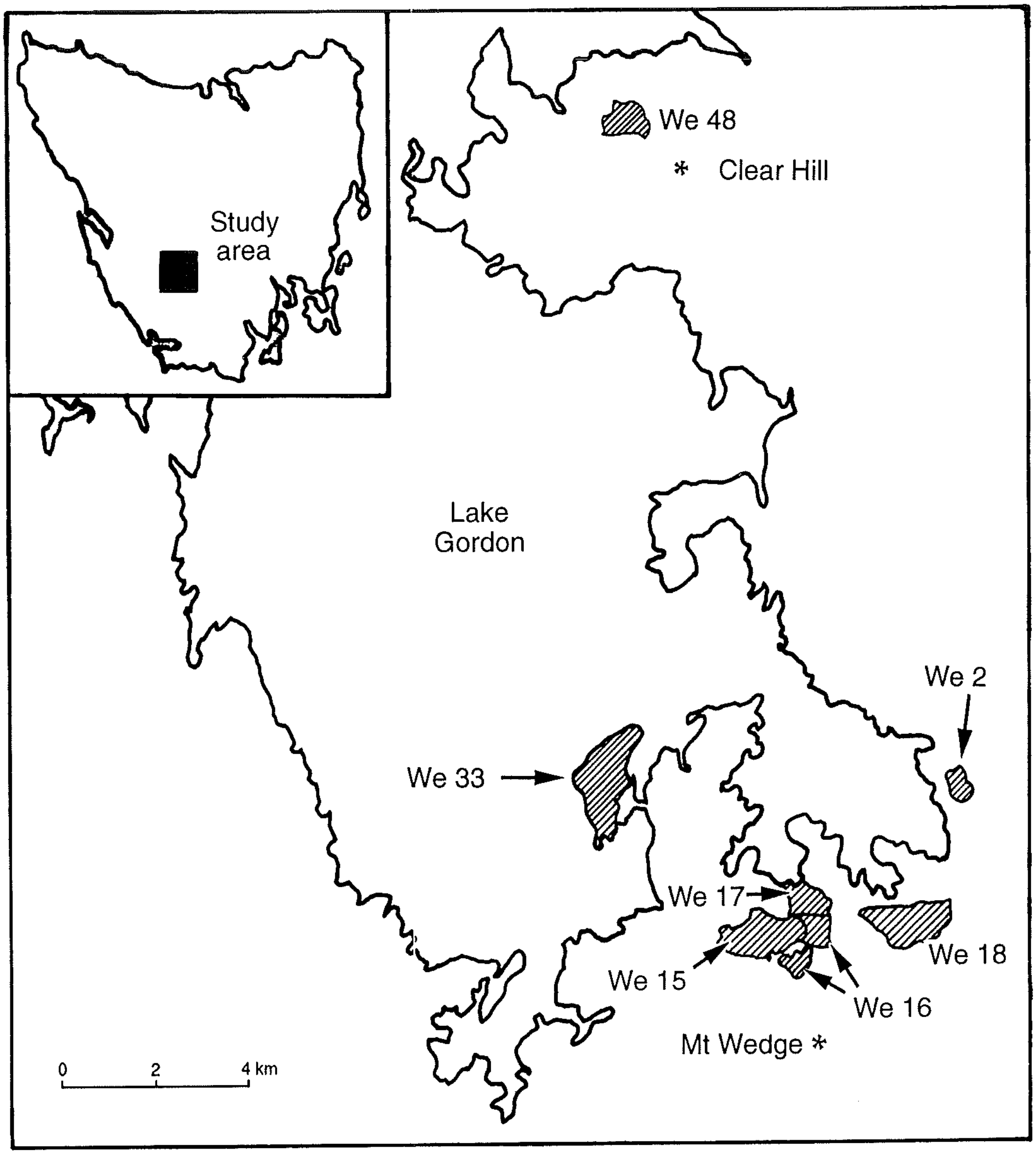

Figure 1. Location of the study area.

sites. The mudstones tend to produce poor mineral soils compared with the rock types of eastern Tasmania, and the quartzites produce extremely nutrient deficient mineral soils (W.D. Jackson, pers. comm.). The sites were between 320 m and 480 m above sea level.

The seven study sites were coupes which have had histories typical of forestry practices in the area. They were Wedge 2 (We 2), Wedge 15 (We 15), Wedge 16 (We 16), Wedge 17 (We 17), Wedge 18 (We 18), Wedge 33 (We 33) and Wedge 48 (We 48). Sawlogs were harvested from the coupes at some stage and all coupes have been clearfelled since 1980 (two-stage logging). Between a few months and several years after clearfelling, the coupes were burnt to encourage eucalypt regeneration and to remove logging slash. The intensities of the burns differed both within and between coupes. The coupes were then aerially sown with eucalypts (*E. regnans* and *E. delegatensis*).

One year after sowing in each coupe, the eucalypt regeneration was surveyed using the methods described below. In three coupes (We 48, We 17, We 33), areas with unsatisfactory regeneration (i.e. understocked areas) were enrichment planted with eucalypt seedlings. These areas comprised less than 10% of each coupe. Surveys in some coupes two years after aerial sowing showed that delayed germination of seed had occurred, and many sites which were enrichment planted carried an adequate stocking of seedlings derived from aerial sowing.

The forest structure of each coupe prior to logging was determined from photo-interpreted (PI) type maps at 1:15 840 scale, derived from aerial photography. A survey of nearby oldgrowth forest of the same PI types suggests that the coupes were virtually all mixed forest before clearfelling. The oldgrowth forests are dominated by *E. regnans*, *E. obliqua* or *E. delegatensis* (the last species at higher altitudes). The understorey is dominated by rainforest species (myrtle, sassafras and leatherwood). On mudstone sites, the rainforest has a callidendrous to thamnic structure while on quartzite, the structure varies from thamnic to implicate on the poorest sites (classification of rainforest follows Jarman *et al.* 1984). Broad-leaved wet sclerophyll shrubs (notably dogwood, musk and blanket bush) co-occur with rainforest species on some sites, and dominate the understorey of regrowth wet sclerophyll forests. Ferns are common on the floor of mixed forest and wet sclerophyll forests, and are conspicuous also as epiphytes in mixed forest.

Survey methods

For this study, the coupes were surveyed five to eight years after regeneration burning. Quadrats were placed at 20 m intervals along parallel transects 100 m or 200 m apart. A total of 965 quadrats was located in the seven coupes.

Regeneration of eucalypts, myrtle, sassafras, leatherwood, celery-top pine, blackwood and silver wattle was recorded for each species as either (1) present in a circle of area 4 m^2, (2) present in a 16 m^2 circle, including the 4 m^2 circle, or (3) absent from the quadrat. Regeneration refers to seedlings of any size, advanced growth or vegetative growth. The quadrat sizes and techniques were consistent with those regularly used to assess stocking rates of eucalypt regeneration in State forest (see Forestry Commission 1991b).

Each quadrat was also classified according to its rock type and the intensity of the regeneration burn on the site. At the time of the survey, it was noted if quadrats were on snig tracks, roads, landings, turning bays or quarries, or if they were unlogged or had been reburnt. Those on snig tracks were treated separately, the others excluded. Ninety quadrats were located on snig tracks, and 50 quadrats were excluded from the analysis because of other disturbance.

The basal rock types (mudstone or quartzite) indicated the relative fertilities of the soils on which regeneration was occurring. They were determined for each quadrat at the time of the survey or from subsequent inspection of the coupes, or from reference to geological maps. A total of 639 quadrats on mudstone and 107 quadrats on quartzite were included in the analysis, and 79 quadrats were excluded because of the uncertainty of geological boundaries.

Fire intensity was categorised as no burn, cool burn, medium burn or hot burn. The intensity of the fire was either estimated at each quadrat (from the amount, size and charring of litter) or where this information was not collected, from burn descriptions and maps which were provided by the forester overseeing the burn. Using the appearance of the quadrat has the potential to be biased by characteristics of the regrowth, but care was taken to avoid this, and the field results correlate well with the descriptions given by the forester for these sites. Using the forester's maps of burn intensity does not delineate the local patchiness in the burn, which is common in low intensity burns. Some of the mapped fire intensity boundaries are approximations, so quadrats which occurred along boundaries between different mapped fire intensities and which were classified only on the basis of maps were excluded from the analysis. Of the quadrats on mudstone included in the analysis, 32 were unburnt, 264 had cool burns, 266 had moderate burns and 77 had hot burns. On quartzite, three quadrats were unburnt, 43 had cool burns, 53 had moderate burns and eight had hot burns.

Data analysis

Calculations were made of the frequencies of quadrats containing regeneration of each taxon within treatment classes (e.g. the frequency of unburnt 4 m^2 quadrats on mudstone containing myrtle regeneration). When expressed as percentages, these are called stocking rates. Comparisons were made between these frequencies with a logistic model using Genstat 5 (1987), assuming a chi-squared approximation to the deviance. This method assumes independence of events. In these analyses, this means that the occurrence of regeneration of a species in a quadrat does not affect the chance of its occurrence in any other quadrat. This assumption is reasonable since quadrats are separated by at least seven times their radius.

Analyses of subsets of the data were made. These included tests of groups of classes and pairwise comparisons of classes. Rainforest species (myrtle, leatherwood, sassafras, celery-top pine) were analysed both as a group and separately. Similarly, in classes where there were very low numbers of quadrats, some fire intensity categories were combined such that no burns and cool burns were called low fire intensities, and medium burns and hot burns were called high fire intensities. Where appropriate, contingency tests between factors were made.

Some of the classes in this analysis are small, especially those on quartzite or on unburnt sites. This has reduced the flexibility and sensitivity of the analysis. The use of presence/absence data prevents conclusions being drawn on the density or vigour of regeneration in quadrats but some qualitative observations are presented.

Results

Figure 2 shows stocking rates, in 4 m^2 quadrats, of eucalypts and of pooled rainforest species (i.e. the proportion of quadrats in each fire and rock type class containing regeneration of myrtle, leatherwood, sassafras or celery-top pine).

Figures 3 and 4 show stocking rates of each of the rainforest species and *Acacia* species in 16 m^2 quadrats. In this study, too few 4 m^2 quadrats contain regeneration of non-eucalypt species to be used statistically to separate treatment classes, and hence 16 m^2 stocking rates are used for these species. Stocking rates on 4 m^2 quadrats showed the same trends as those on 16 m^2 quadrats.

Conclusions for the three variables examined are summarised below.

Fire intensity

Eucalypts. On mudstone, the 4 m^2 stocking rates of eucalypts after hot burns were significantly higher than those on unburnt sites (Fig. 2a). There is no evidence of differences in stocking rates on quartzite between low and high fire intensities.

Rainforest species. There is strong evidence that the 4 m^2 stocking rates of rainforest species on unburnt or cool burnt sites are significantly higher than on medium and hot burnt sites on both mudstone and quartzite (Fig. 2b).

Analysis of 16 m^2 stocking rates indicates that myrtle, leatherwood and sassafras have higher regeneration stocking on sites after lower intensity burns (Figs 3a, 3b and 3c) than after higher intensity burns. This trend is

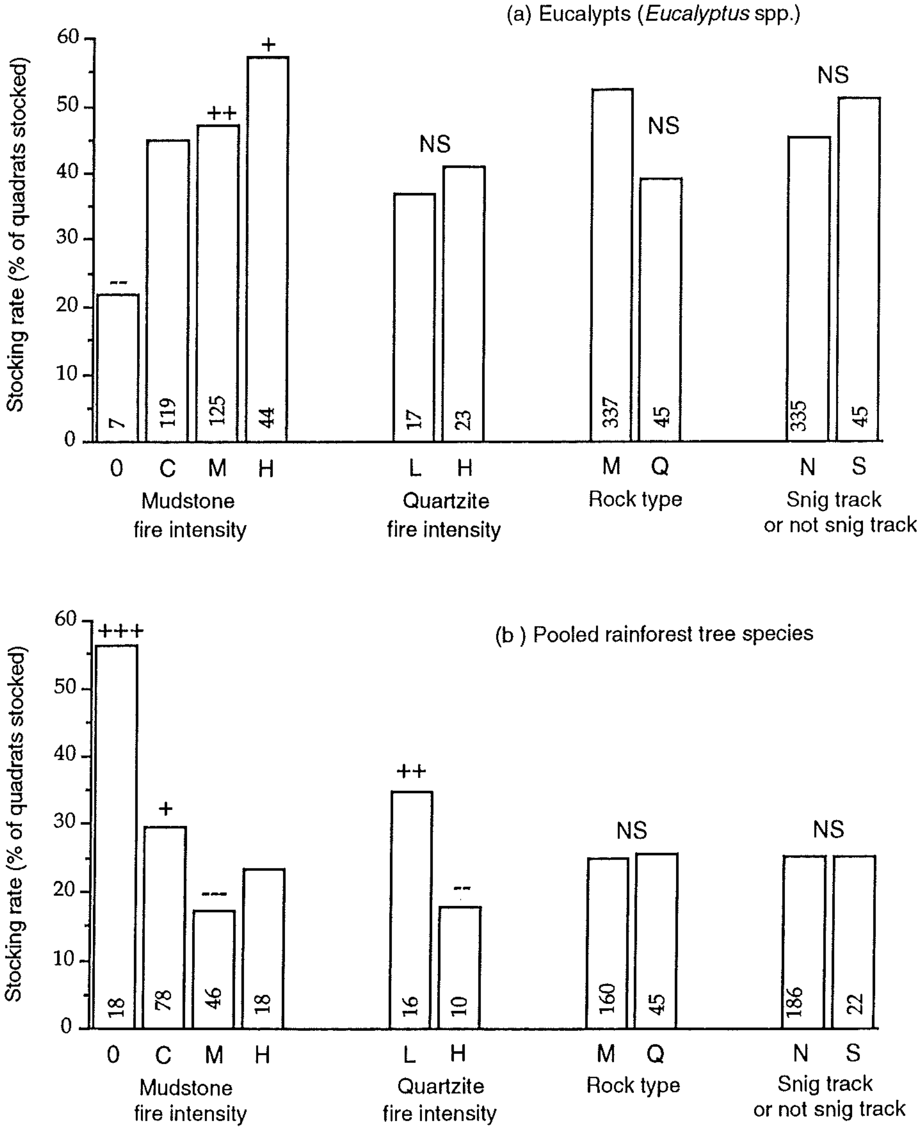

Figure 2. Stocking rates (percentages of quadrats containing regeneration) of different classes of 4 m^2 quadrats for (a) eucalypts, and (b) rainforest tree species (myrtle, sassafras, leatherwood or celery-top pine). The number of quadrats containing the species is shown in the bottom of the column for each class.

Abbreviations:

(1) ***Fire intensity.*** *O = unburnt, C = cool burn, M = medium burn, H = hot burn on mudstone or medium to hot burn on quartzite, L = unburnt or cool burn;*

(2) ***Rock type.*** *M = mudstone, Q = quartzite;*

(3) ***Snig tracks.*** *S = on a snig track, N = not on a snig track;*

(4) ***Significance levels.*** *NS = not significant; +, ++, +++ = significantly high at .05, .01 and .001 levels respectively; -, --, --- = significantly low at .05, .01 and .001 levels respectively.*

most pronounced for myrtle. The lack of significant difference between stocking rates of celery-top pine (Fig. 4a) on high and low fire intensity quadrats probably reflects the small class sizes, and possibly the fact that seed of this species is distributed by animals (mainly birds) which would be utilising a range of environments in the study area.

***Acacia* species.** There is evidence that regeneration of blackwood is significantly lower on high fire intensity sites (Fig. 4b) and significantly higher on sites which have received cool burns. A similar trend is apparent for silver wattle (Fig. 4c).

Rock types

Contingency tests of rock type versus fire intensity showed no evidence that these two factors are associated. Pooling fire frequencies to compare regeneration on different rock types is therefore valid. There is strong evidence of preference for mudstone by blackwood (Fig. 4b), silver wattle (Fig. 4c) and leatherwood (Fig. 3b).

No significant differences existed in the stocking rates of eucalypt regeneration on mudstone or quartzite. However, substantial differences in the size and vigour of eucalypt seedlings and saplings were observed. Mudstone sites typically carried tall (to 5 m), vigorous regeneration. Regeneration on quartzite sites was typically stunted, except for advanced growth on sites where the regeneration burn had failed or had been of low intensity.

Snig tracks

Snig tracks are probably best treated as being composed of several parts, with different regeneration characteristics being related to drainage, degree of compression and other attributes (see Williamson 1990). Partitioning of snig tracks into components was not undertaken in this study. However, on a broad scale, there are no significant differences in stocking rates between snig tracks and other sites except for silver wattle (Fig. 4c) where the stocking rate in quadrats encompassing snig tracks was significantly higher.

Discussion

In mature forest, densities of eucalypts and most other tree species are well below one per 16 m^2. Only a proportion of seedlings will achieve maturity, so the stocking rate in a recently regenerated coupe needs to be greater than the stocking rate of mature forest. Estimates have been made of optimum stocking levels of eucalypt regeneration to establish suitable stocking levels in mature forest (Lockett, undated). These recommended stocking rates will not necessarily apply to other species of trees, since the frequency of these species in mature forest differs from that of eucalypts, different proportions of these species will survive from seedling stage to mature trees, and some rainforest species, in particular, may regenerate later. However, it is possible to make some generalisations about the relationship between the surveyed stocking rates and the species density in mature forest for each species, by comparing the known ecology of a species with that of eucalypts. The estimates given by Lockett (undated) require that a high proportion of eucalypt seedlings reach maturity. Tasmanian rainforest species in general are relatively shade tolerant (Read 1985) and many established seedlings are likely to achieve maturity in spite of being overtopped by eucalypts. Leatherwood and myrtle have short dispersal distances and are likely to regenerate best after disturbance (Hickey *et al.* 1982), and hence initial stocking levels probably determine the long-term potential stocking. However, mortality may be higher than for eucalypts, due to slower growth rates allowing relatively more damage from grazing. Hence, myrtle and leatherwood probably have slightly lower rates of survival of seedlings than eucalypts. The long-term potential is harder to assess for sassafras which is often grazed heavily (Hickey 1982) but is moderately well dispersed and more

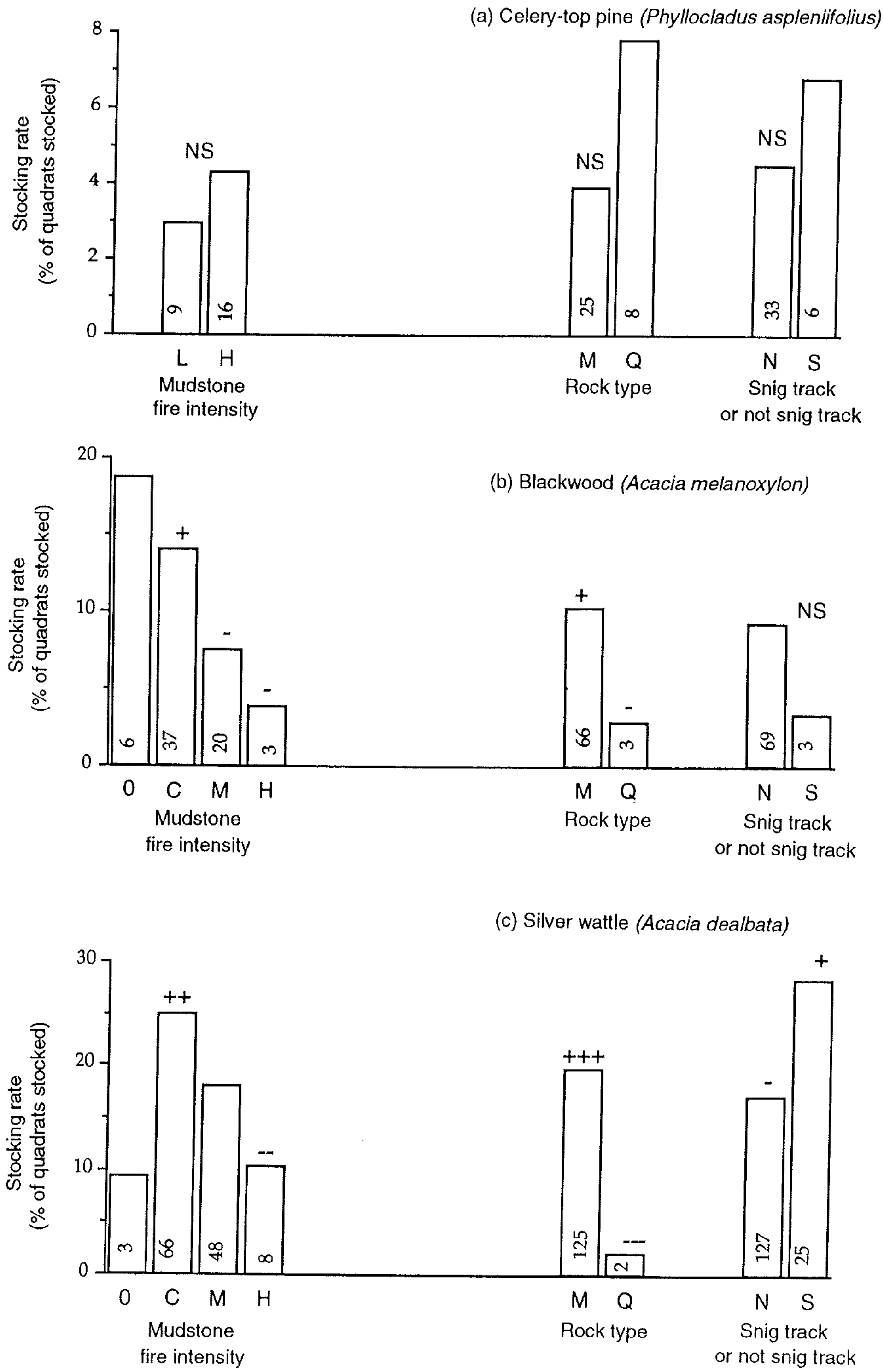

Figure 3. Stocking rates (percentages of quadrats containing regeneration) for different classes of 16 m^2 quadrats for myrtle, leatherwood and sassafras. The same symbols are used as in Figure 2.

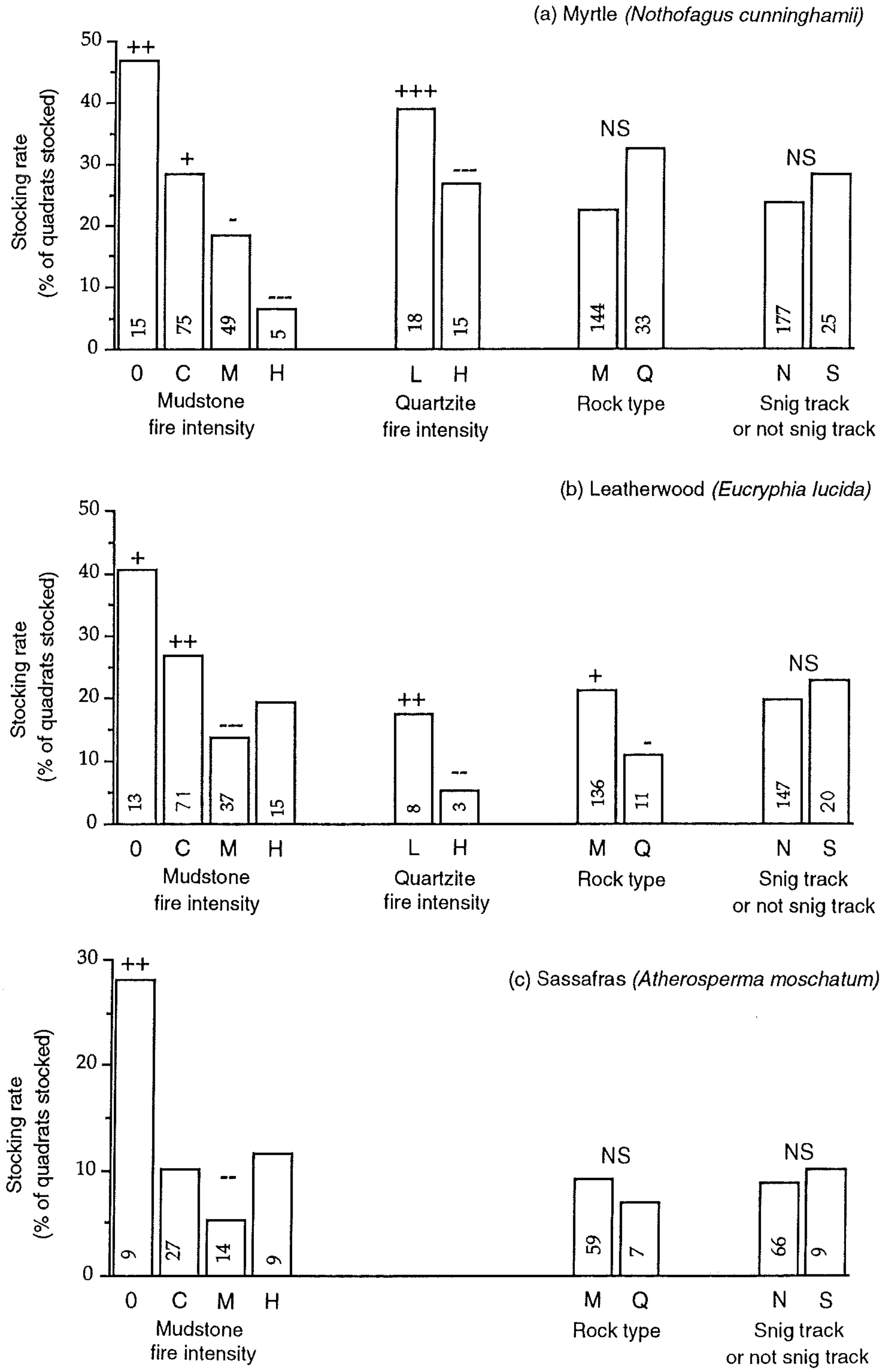

Figure 4. Stocking rates (percentages of quadrats containing regeneration) for different classes of 16 m^2 quadrats for celery-top pine, blackwood and silver wattle. The same symbols are used as in Figure 2.

shade tolerant than myrtle or leatherwood (Read 1985). There is evidence of gap-phase regeneration of myrtle, leatherwood and sassafras in undisturbed rainforests (Read and Hill 1988) but this can only occur if propagules are available, and will not alter the general forest composition until sclerophyll species die and light gaps are created. The density of each of these tree species in mature mixed forest in the Clear Hill/Mount Wedge area is of the same order as the density of eucalypts. Therefore, trends seen in stocking levels of these rainforest species reflect the likely composition of the regrowth forests in the study area, at least until the wet sclerophyll understorey species die out, which is not likely to occur for at least 80 years.

Eucalypts

Lockett (undated) recommends that in surveys conducted about one year after sowing, optimum 4 m^2 stocking rates for eucalypts are between 18 and 30% for future sawlogs, and between 30 and 65% for future pulpwood. The stocking levels of eucalypts for each class in the Clear Hill/Mount Wedge coupes are within the range for future pulpwood except on unburnt mudstone, but are higher than is considered desirable for future sawlogs except on unburnt sites. However, there is considerable uncertainty in the estimates of overall stocking in classes with small numbers of quadrats, such as unburnt mudstone. Pooling of mudstone and quartzite sites gives a stocking rate of about 30% for unburnt sites. The current study is on sites five to eight years after burning, when attrition of some of the initial (zero to two-year) eucalypt regeneration could be expected; that is, the stocking levels of five- to eight-year-old regeneration are probably equivalent to higher stocking levels of one-year-old regeneration on sites where enrichment planting has not been undertaken. A small proportion of the eucalypt regeneration recorded from some coupes in the current survey would originate from in-fill planting on areas identified as understocked after the one-year regeneration survey.

High stocking rates are of dubious value, since they can cause competition between trees and hence reduce productivity. Eucalypt stocking levels on sites subjected to high intensity regeneration burns are towards the upper limit for pulpwood (65%), and may be excessive since the levels are based on five- to eight-year-old regeneration. They are above the level recommended for sawlog production (35%) after any fire at all. This suggests that thinning may be required in the future, particularly on sites receiving hot burns, if sawlog harvesting remains the main priority for timber production in wetter forests in the area.

Generally, the regeneration of eucalypts on unburnt sites occurs immediately after logging. However, when a regeneration burn is undertaken, there is generally a gap of several months to years between logging and regeneration, and hence a loss of growing time. Lockett and Candy (1984) suggest that in wetter areas of Tasmania, this loss of growing time is compensated for by higher growth rates after a regeneration burn, caused by the stimulus to seedling growth known as the ashbed effect. However, the wet sites used in their analysis were on dolerite which produces soils of relatively high fertility, and their dry sites were on soils derived from Mathinna sediments which are less fertile. The rock types in the Clear Hill/ Mount Wedge area, particularly the quartzites, are relatively infertile and hence the fertility of forest soils will be much more determined by the accumulation of organic material. The loss of soil nutrients from the system due to regeneration burning (Harwood and Jackson 1975) seems likely to reduce the potential promotion of growth by fire. Therefore, the results of Lockett and Candy (1984) for wet sites are not necessarily valid on these western Tasmanian rock types, and it cannot be assumed that regeneration after fire would overtake post-logging advanced growth, especially on quartzite sites. Eucalypts on unburnt quartzite quadrats eight years after the regeneration burn (parts of coupe We 2) are many times the height of eucalypts on burnt quartzite quadrats of the same age (from adjacent parts of We 2 and from We 15). Many of the burnt quartzite sites are also characterised by ground surfaces which are bare or have a high cover of bryophytes.

Acacia *species*

Blackwood and silver wattle, like eucalypts, regenerate after disturbance and have rapid early growth. Hence, they compete well for light. Blackwood appears to be prone to early grazing but at the time of these surveys, both blackwood and silver wattle seedlings tended to be tall enough to be well established and out of reach of ground-living grazers. Therefore, a relatively high proportion of surveyed seedlings are likely to reach maturity, and the stocking standards for eucalypts should be broadly applicable to blackwood and silver wattle. They have a relatively short life span, but their soil-stored seeds have very long viabilities and they can remain a part of a forest system long after the death of all adults (Gilbert 1959; Cunningham and Cremer 1965).

Rainforest tree species

Rainforest species achieve the stocking levels considered satisfactory for eucalypts only on sites which are unburnt or have cool burns. Optimum eucalypt stocking levels can only be taken as rough estimates, since higher stocking levels may be desirable for pooled rainforest species because they have higher densities in mature mixed forest. The ability of rainforest species to regenerate under a eucalypt canopy suggests that the continuous regeneration, and ultimately the dominance of rainforest species in the understorey, will be facilitated by high initial stocking rates of these species. This will result in a relatively rapid shift from a flammable sclerophyllous understorey to a less flammable rainforest understorey, thereby decreasing the vulnerability to wildfire of the regrowth coupes.

There are two possible explanations of the relationship between regeneration rates of rainforest species and the intensity of regeneration burns.

(1) High intensity fires may inhibit the regeneration of rainforest species and promote sclerophyll species. This would be true if fire intensities were determined by factors independent of vegetation type, such as forestry practices and weather conditions before and during the fire.

(2) Fire intensity may be determined by the pre-fire vegetation, with sclerophyll understoreys producing more intense burns, and mixed forest understoreys producing low intensity burns. If this were true, the differences between the vegetation regenerating on different sites could be explained by each vegetation type tending to regenerate into similar vegetation, perhaps due to the availability of viable seeds. That is, mixed forest would produce low intensity burns which would not kill its seedstock, and would then regenerate into mixed forest. By contrast, wet sclerophyll forests, having more flammable overstoreys, understoreys and litter, would produce more intense burns and then regenerate to this type because of the local abundance of seeds which can resist fire (e.g. blackwood, silver wattle and dogwood seeds) or are wind dispersed (e.g. musk).

It is likely that both explanations are partly correct. Proposal (2) alone cannot adequately explain the results in this paper. Pre-logging vegetation was almost all mixed forest, with only a small proportion of wet sclerophyll species. There was not enough wet sclerophyll forest to create the proportion of intense fires and the areas of poor regeneration of rainforest species found in the study sites. Forestry practices clearly have a major effect on the regeneration burn. The choice of firing time, the amount of wood and slash left after clearing and the choice of two-stage versus single-stage logging all affect fire intensity. Therefore, forestry practices must influence

Fire intensity	Unburnt	Cool		Medium	Hot
	←	— — — —	— — — —	— — — —	→
Rainforest tree regeneration	*good*	*poor*		*very poor*	
Eucalypt (for pulpwood)	*patchy, understocked*	*adequate*	*good*	*very good*	*overstocked*
Eucalypt (for sawlog)	*patchy*	*overstocked*		*very overstocked*	

Figure 5. Stocking rates of regeneration of rainforest tree species and eucalypts relative to regeneration burn intensity.

the regeneration of the rainforest tree species, with practices which reduce fire intensity significantly improving the regeneration of these species.

The relative levels of regeneration of eucalypts and rainforest trees in the Clear Hill/Mount Wedge area and the implications for wood production are summarised in Figure 5.

Regeneration of mixed forest after clearfelling is desirable for several reasons. The non-eucalypt components of mixed forest in the Clear Hill/Mount Wedge area are of greater economic value than those of wet sclerophyll forest. Myrtle, celery-top pine and sassafras are valuable timbers, and leatherwood is one of the mainstays of the honey industry. Blackwood and silver wattle both provide timber and occur in both mixed forest and wet sclerophyll forest. However, most wet sclerophyll species are not noted for their economic value. Dense understoreys of wet sclerophyll shrubs may compete more effectively with eucalypt regeneration than understoreys dominated by slower growing rainforest species (Cunningham and Cremer 1965). The relative flammabilities of rainforest and wet sclerophyll understoreys have already been discussed.

Mixed forest is more vulnerable than wet sclerophyll forests to long-term ecological changes resulting from logging because it occurs at a later stage in the successional sequence. It supports species of plants and animals which require niches associated with older forests and the presence of rainforest trees. These niches include hollows and fissures in trees and stags, decomposing logs on the forest floor and the development of deep organic soils. The presence of rainforest species as components of eucalypt forest is also considered by many people to have aesthetic value. Observations in different areas of Tasmania suggest that the combination of clearfelling of mixed forest and hot regeneration burns typically results in regrowth eucalypt forests having an understorey dominated by wet sclerophyll shrubs rather than rainforest species.

Achieving regeneration of all mixed forest tree species after logging requires some compromise to be made on fire intensity. In the Clear Hill/Mount Wedge area, adequate regeneration of most of the rainforest species seems only attainable with no regeneration burn or after low intensity fires, whereas eucalypt regeneration may be poor or patchy without fire. These results may be extended with caution to other areas of mixed forest. The relationships of rainforest tree species regeneration to fire intensity appear to apply generally (see for example Cunningham and Cremer 1965; Taplin 1982; Felton and Lockett 1983; Neyland and Hickey 1990), since they seem to be related to such features as sensitivity of seeds to fire. However, the relationships of eucalypt regeneration to fire intensity will probably vary between areas, since they seem also to be related to factors such as the type of parent rock and climate.

The results presented here have several limitations, and should be considered as preliminary. Work currently in progress includes comparison of logged and burnt sites with unlogged sites burnt by wildfire (John Hickey, pers. comm.). This will enable estimates to be made of natural regeneration densities of eucalypt and non-eucalypt species.

Results obtained from single-stage logging may differ from those using two-stage logging, as was undertaken in the coupes surveyed. Additional surveys of eucalypt and non-eucalypt regeneration following logging of mixed forest are warranted, as the results obtained from this study have economic, silvicultural and ecological implications. Such surveys would be facilitated if detailed information were available on forest structure and composition prior to logging.

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References

Ashton, D. H. (1981) Tall open-forests. In: *Australian Vegetation* (ed. R.H. Groves), pp. 121-151. Cambridge University Press, Cambridge.

Barker, M. J. (1991) *The Effect of Fire on West Coast Lowland Rainforest.* Tasmanian NCRP Technical Report No. 7. Forestry Commission, Tasmania, and Dept. of the Arts, Sport, the Environment, Tourism and Territories, Canberra.

Cremer, K. W. and Mount, A. B. (1965) Early stages of plant succession following the complete felling and burning of *Eucalyptus regnans* forest in the Florentine Valley, Tasmania. *Aust. J. Bot.* 13: 303-322.

Cunningham, T. M. and Cremer, K. W. (1965) Control of the understorey in wet eucalypt forests. *Aust. For.* 29: 4-14.

Felton, K. and Lockett, E.J. (1983) Silvicultural practice in Tasmanian eucalypt forests. In: *Facing Forestry's Future,* pp. 111-114. Paper pre-prints of the 10th Institute of Foresters of Australia Conference. University of Melbourne, 29th Aug.-2nd Sept. 1983.

Forestry Commission (1991a) *Blackwood.* Native Forest Silviculture Technical Bulletin No. 10. Forestry Commission, Tasmania.

Forestry Commission (1991b) *Regeneration Surveys and Stocking Standards.* Native Forest Silviculture Technical Bulletin No. 6. Forestry Commission, Tasmania.

Genstat 5 (1987) Rothamstead Experimental Station, Hertfordshire, England.

Gentilli, J. (1972) *Australian Climatic Patterns.* Nelson, Melbourne.

Gilbert, J. M. (1959) Forest succession in the Florentine Valley, Tasmania. *Pap. Proc. R. Soc. Tasm.* 93: 129-151.

Harwood, C. E. and Jackson, W. D. (1975) Atmospheric losses of four plant nutrients during a forest fire. *Aust. For.* 38: 92-99.

Hickey, J. E. (1982) Natural and artificial regeneration of some Tasmanian rainforest trees. In: *Tasmanian Rainforests: Recent Research Results.* Forest Ecology Research Fund, Forestry Commission, Tasmania.

Hickey, J. E., Blakesley, A. J. and Turner, B. (1982) Seedfall and germination of *Nothofagus cunninghamii* (Hook.) Oerst., *Eucryphia lucida* (Labill.) Baill. and *Atherosperma moschatum* Labill. Implications for regeneration practice. *Aust. For. Res.* 13: 21-28.

Hill, R. S. and Read, J. (1984) Post-fire regeneration of rainforest and mixed forest in western Tasmania. *Aust. J. Bot.* 32: 481-493.

Jackson, W. D. (1965) Vegetation. In: *Atlas of Tasmania* (ed. J. L. Davies), pp. 30-35. Lands and Surveys Department, Hobart.

Jackson, W. D. (1968) Fire, air, water and earth – an elemental ecology of Tasmania. *Proc. Ecol. Soc. Aust.* 3: 9-16.

Jarman, S. J., Brown, M. J. and Kantvilas, G. (1984) *Rainforest in Tasmania.* National Parks and Wildlife Service, Tasmania.

Lockett, E. J. (undated) The Interpretation of Regeneration Survey Data. Unpublished report, Forestry Commission, Tasmania.

Lockett, E. and Candy, S. G. (1984) Growth of eucalypt regeneration established with and without slash burns in Tasmania. *Aust. For.* 47: 119-125.
Neyland, M. and Hickey, J. (1990) Leatherwood silviculture – implications for apiculture. *Tasforests* 2: 63-72.
Read, J. (1985) Photosynthetic responses to different light regimes of the major canopy species of Tasmanian cool temperate rainforest. *Aust. J. Ecol.* 10: 327-334.
Read, J. and Hill, R. S. (1988) The dynamics of some rainforest associations in Tasmania. *J. Ecol.* 76: 558-584.
Taplin, R. E. (1982) Rainforest survival: A search for rainforest species in regeneration coupes of the Hastings Forests in southern Tasmania. In: *The Tasmanian Rainforest Estate* (ed. R. Jones). Environmental Studies Occ. Pap. 15. University of Tasmania, Hobart.
Williamson, J. R. (1990) *The Effects of Mechanised Forest Harvesting Operations on Soil Properties and Site Productivity.* Research Report No. 5. Tasmanian Forest Research Council, Hobart.