Review of the impact of retained overwood trees on stand productivity

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Summary

Competition between trees for resources such as light, nutrients and water is a significant process in a forest. Because these resources are limited, a forest site has a maximum productive capacity, and its resources must be shared between all trees. This sharing is not necessarily equal, with canopy position and the ability of a tree to capture resources dictating its competitive status in the stand. As a result, a tree with a favourable position or size advantage can ultimately suppress its neighbours. Similarly, following harvesting, retained eucalypt stems will exert a suppressive influence on regrowth in terms of stocking, and height and volume growth. This effect has been the subject of several studies in Australia, aimed primarily at quantifying it in terms of a 'zone of influence' or loss of potential biological and commercial productivity. These studies have shown that the zone of influence on regrowth around a retained eucalypt tree following harvesting is typically 1.7 to 3.0 times its crown radius, with 25% of harvested area influenced if 5 trees/ha are retained. Regrowth volume and height growth losses can be in the order of 15 to 50% when 10-30% basal area is retained, compared to clearfelling.

Introduction

Competition for site resources between living components in a forest is an ecologically significant process (Raven *et al.* 1981) and forest trees are no exception (Ashton 1975, 1976; Florence 1996). It is also well known that a particular forest site has a limited amount of available resources, such as light, soil nutrients and moisture (Ashton & Turner 1979; Ashton & Willis 1982; Attiwill and Leeper 1987), and that this dictates site productive capacity (Raison *et al.* 1991; Florence 1996). Perhaps the best demonstration of competition is expressed by trees that occupy favourable positions in a forest stand, maintain a strong competitive advantage, and ultimately dominate and effectively suppress growth of neighbouring trees.

Such an advantage in a forest is often related to relative height and canopy position. For example, where a tree with a healthy crown stands taller than all other forest components, light is less limited and its capacity to photosynthesise and grow will be largely restricted by its ability to extract soil water and nutrients. In the case of a large, long-established veteran tree, this demand for resources can be substantial, even if the tree is in decline (Attiwill and Leeper 1987).

In native forest reserved for timber production in Victoria, trees may be retained on a harvested area as a source of seed, habitat, landscape, shelter, accelerated diameter increment following release, or if they are unmerchantable. For example, the Code of Forest Practices for Timber Production (NRE 1996) requires that local Forest Management Plans and Prescriptions consider retention of habitat trees following harvesting in appropriate numbers and configurations. Although these may have a considerable impact on the commercial productivity of the regenerating stand, a prescription of 15 habitat trees per 10 ha of harvested forest, for example, is considered acceptable by commercial forestry interests. However, the issue remains a concern given the call to increase numbers of live retained habitat or potential habitat trees (Lindenmayer 1996), and the claim that these trees have not been demonstrated to significantly reduce commercial productivity of harvested areas (Gibbons & Lindenmayer 1996, 1997).

Numerous site occupancy or competition measures have been used to determine site productivity and to estimate potential commercial production losses associated with retaining non-commercial trees. The competitive impacts of retained trees will vary depending on their location and distribution within the forest coupe. Thus, the impacts of individual, scattered, clumped and edge trees are reported here. Note there is a distinction between trees that are required live for long term purposes (eg. habitat) and trees required for short-term purposes, beyond which time they could be removed or destroyed during site preparation. This paper attempts to assess the impact on site productivity of live 'non-commercial' trees retained for long periods with respect to commercial wood production at the coupe level. Apart from some comments added to encourage thought on the subject, this paper does not attempt to quantify the impact on overall sustainable production.

Discussion

Even-aged stands stocked to achieve maximum growth

Basal area provides a convenient means of assessing site occupancy and productive capacity. Work done in Scandinavian forests (Langsaeter 1941, cited in Florence 1996) identified some fundamental principles which should underlie any discussion of site stocking. Langsaeter plotted annual gross volume increment against stocking (volume per hectare) and found that annual increment was unaffected by stocking across a wide range of stocking values. Opie (1969) summarised those findings as follows: "the models indicate that growth per unit area increases with increase of residual stocking until maximum growth is reached usually at a density of about half of the highest stocking possible. With increase of stocking beyond this, growth remains maximal until near the highest stocking possible so that the model has a long 'plateau', or it may decline at a moderately high stocking, especially on poorer sites." The stocking level at the point where the growth begins to decline, due to intense competition, is commonly termed ‘fully stocked’, and its basal area for eucalypt forest is termed ‘reference basal area’ in Victoria (NRE 1997). Daniel *et al.* (1979) provide an extensive discussion of the subject.

From a total stand perspective, commercially non-productive trees (no sawlog value) contribute to overall productivity and will respond in the same manner as productive trees. However, from an economic perspective, site resources being utilised by these non-commercial trees will be to the detriment of those trees of commercial value.

While maximum site productivity is maintained over a broad range of stocking (stems/ha), the proportion of stand occupied by each tree is inversely proportional to the number of trees present on the site. Regardless of a tree’s commercial value, a single tree of a given diameter is expected to exhibit twice the diameter increment in a stand maintained at 50% of full stocking compared to the same tree in a fully stocked stand. For a range of stockings within the zone of maximum growth, Table 1 illustrates the percentage of commercial stem volume lost due to the presence of a non-commercial tree, using the assumption that tree volume is directly proportional to basal area.

Table 1 does not accurately reflect the growth losses which occur with the retention of non-commercial trees of a different competition status to the surrounding commercially productive trees (eg. potential sawlog regrowth). Opie (1969) identifies the status of the subject tree within the stand as one of the two main components to be taken into account in deriving competition indices. For example, if the non-commercial stems are in the dominant class and the commercial stems are in a lower canopy class then the impact of retained trees on commercial growth may be underestimated by Table 1.

Table 1. Percentage of volume loss per hectare due to the retention of a single tree of a particular diameter for various stand stocking levels.

Retained tree		Production loss (%) for a given stand stocking			
Diameter (cm)	Basal Area (m^2/tree)	50 m^2/ha	40 m^2/ha	25 m^2/ha	15 m^2/ha
50	0.20	0.40	0.50	0.80	1.33
75	0.44	0.88	1.10	1.76	2.93
100	0.79	1.58	1.98	3.16	5.27
125	1.23	2.46	3.08	4.92	8.20
150	1.77	3.54	4.43	7.08	11.80
200	3.14	6.28	7.85	12.56	20.93

Overwood retention following harvesting

Overwood here refers to trees retained post-harvesting, resulting in a eucalypt stratum standing over subsequent eucalypt regeneration. The effects of retained overwood on the productivity of regeneration can be discussed in terms of the impact of individual trees and their zones of influence, and of different stocking distributions of retained overwood across a given area. The canopy cover exerted by retained overwood will vary with its stocking, height, tree diameter and hence crown size and diameter.

Zone of influence

Zone of influence is the area surrounding an individual tree which contributes resources to that tree’s development and growth, and is therefore subjected to competition for the available resources from any neighbouring trees with overlapping zones. The simplest example of the zone of influence is demonstrated by the low stocking or absence of regeneration directly below the crown of a tree. Within the crown projection of all eucalypts, the number of surviving seedlings *decreases* markedly closer to the trunk (Florence 1996), even though they may have germinated from seedfall, the quantity of which is known to *increase* along that continuum (Cremer *et al.* 1978; Campbell *et al.* 1990; Bassett 1996). For some eucalypts there is commonly no surviving regeneration within crown projection, such as for Eucalyptus camaldulensis (river red gum) (Opie 1969; Dexter 1967, 1978).

However, the boundary of crown extent does not necessarily define the zone. Bi and Jurskis (1997) found this boundary to delineate the minimum zone of influence. Thus, the zone of influence of a tree may be more accurately defined as the total area over which the tree obtains, or competes for, site resources. The maximum zone of influence is defined as the area that may be utilised for site resources by a tree when unrestricted by competition (Opie 1968).

Incoll (1979), Rotheram (1983), Kellas *et al.* (1996) and Bi & Jurskis (1997) all studied the impact of overwood on the productivity of an understorey of regrowth in *E. sieberi* (silvertop ash, Victoria), *E. diversicolor* (karri, Western Australia), *E. tricarpa* (red ironbark, Victoria), and *E. fastigata* (brown barrel, New South Wales) respectively, describing zones of suppressive influence for each species. Similar results were obtained between all studies, with the exception of Incoll (1979), who recorded the greatest zone of influence with an average radius of 4 to 6 crown radii around the subject tree. In contrast, Opie (1969) indicated the radius of the zone of influence to be approximately 2 crown radii. That is, substantially smaller.

The subject trees chosen for study by Incoll (1979) all had healthy, full crowns, and zones of influence were assumed to be circular. It is acknowledged here that these are more indicative of seedtrees, and although the intention is not to retain them long-term, many such trees are currently being retained indefinitely, due to operational constraints. However, with respect to habitat trees, Incoll (1979) may have potentially over-estimated the radius of zones of influence, given that retained trees with poor, senescent crowns and those subjected to crown degrade, wind-throw or other mortality will have a lesser and likely non-circular effect. In contrast, Bi & Jurskis (1997) used 56 randomly chosen old-growth habitat trees, displaying a wide range of crown health and senescent characters that could be considered more indicative of natural stands. Their average zone radius (Z) was slightly less that 2 crown radii (1.7-1.8 CR), with a maximum defined by $\ln Z = 1.21 + 0.65 \ln CR$ (R^2 96%). This contrast suggests that the zone of influence will be effected by the vigour of the residual tree and the availability of site resources.

However, even when using the more conservative estimates, the proportional area of regeneration under the suppressive influence of scattered overwood is quite substantial. For example, using the equation produced by Bi & Jurskis (1997), if

5 well-spaced eucalypt trees per hectare were retained with a typical crown radius of 7 m, approximately 25% of harvested area will be influenced. In terms of reduced height and volume growth, this can represent a substantial loss in productivity.

The growth losses within the zone of influence as observed by Incoll (1979) and Dignan[1] (unpublished data) were substantial and similar for different eucalypt species. Height suppression ranged from about 3 to 30 % within 1 to 4 crown radii. Rotheram (1983) observed a much greater impact close to the subject tree with a reduction in regrowth height of 7 to 25% within a 1 to 1.5 crown radii. In these studies height growth and stocking reduced to almost zero directly beneath overwood crowns, an observation also made by Bi & Jurskis (1997).

Operationally, overwood stem diameter as an estimator of zone of influence is a simpler measure to apply than crown radius. However, crown radius more widely reflects the zone of influence. Dignan (unpublished data) observed a relationship between crown dimensions and growth losses similar to that of Incoll (1979), even though the former overwood stem diameters were 2 or 3 times larger, with poorer crowns partly composed of epicormics. Bi & Jurskis (1997) found that variations in zone of influence increased with increasing tree size, and that crown radius was the only variable that adequately explained this variation. Although crown to stem diameter ratios (crown ratios) can be calculated for particular individual studies, broad application is confounded since stem to crown correlations vary between species, site qualities and stand structures (Applegate *et al.* 1988; Bassett & White 1993). For example, the crown diameter of open grown *E. obliqua* (messmate) was recorded as almost twice that of trees of the same stem diameter growing under maximum stocking conditions elsewhere (Curtin 1964).

Curtin (1964) also observed that crown diameter is influenced by height. It is therefore expected that site quality will affect stem diameter to crown diameter ratios. Opie (1968) described zone of influence radii in *E. camaldulensis* between 14 and 17 times DBHOB, (i.e. radius of zone of influence is about twice crown radius), with the largest zone of influence found on the lowest site quality.

The above studies have used measurement of regrowth to estimate the zone of influence. However, perhaps the strongest demonstration of competition is represented by the accelerated growth of remaining trees following the removal of a proportion of the stand. Kellas *et al.* (1982; 1996) assessed the response of the subject trees to progressive reductions in competition by removal of regrowth and mature trees in a stand of *E. tricarpa* and demonstrated that zones of influence extend over a radius of between 16.5 and 25 times the stem diameter. For *E. obliqua*, Kellas *et al.* (1987) assumed a zone of influence of radius 16.5 times stem diameter, based on previous work by Opie (1968), and subject trees showed a significant growth response when competition within this zone was removed.

While a universal relationship between overwood stem diameter and volume loss on trees within the zone of influence cannot therefore be developed, Table 2 presents specific results from two studies which attempted to estimate losses.

Table 2. Percentage of regrowth volume loss per hectare as influenced by the presence of overwood trees, based on Incoll (1979) and Rotheram (1983). CD = crown diameter, Est. CD = estimated crown diameter, Est. ZOI = estimated zone of influence (radius from stem in metres).

Overwood characteristics				[a] Regrowth volume loss/ha/overwood-tree			
DBHOB (cm)	BA (m^2/ha)	CD (m)	Est.[a] CD (m)	*E. sieberi* Incoll (1979)	Est. ZOI	*E. diversicolor* Rotheram (1983)	Est. ZOI
[a] 50	0.20	7.5		1.9 %	23 m		
75	0.44		11	4.4 %	33 m	1.2 %	11 m
100	0.79		15	7.8 %	45 m	3.4 %	15 m
150	1.77		22			7.6 %	22 m

[a] Derived assuming a CD:DBHOB ratio of 15 per Jacobs (1955).

Operationally, the results from Incoll (1979) could be considered to *represent worst case growth losses for mixed species* and other forests with a reference basal area of about 45 m^2/ha. 'Mixed species' refers generally to the multi-aged sclerophyll forests, dominated by the more tolerant eucalypt species – with such mixes as *E. obliqua*, *E. globulus* (blue gum) *E. radiata* (narrow-leaf peppermint) and *E. viminalis* (manna gum) or *E. sieberi*, *E. globoidea* (white stringybark) and *E. baxteri* (brown stringybark). For up to 5 trees per hectare, Incoll (1979) postulates that the effect will be additive. However, other studies presented here most likely provide more realistic estimates of overwood suppression for eucalypts. They indicate an average zone of influence of radius equal to 1.7-3.0 crown radii. With multiple overwood stem retention, the subsequent affected area and growth and stocking losses can be operationally and economically significant, with likely implications for the determination of sustainable yields.

Overwood studies considering tree stocking

The clearfell with slash burn silvicultural system, which has no retention of overwood, has been demonstrated to establish the most productive regrowth forest in terms of establishment and early growth of wet sclerophyll eucalypts. (Lockett and Candy 1994; King *et al.* 1997; Campbell & Bray 1987; Ashton 1976). These studies demonstrate early growth suppression of *E. regnans* seedlings under harvesting systems alternative to clearfelling-where 30%, 50%, or 100% of the canopy is retained as shelterwood.

In mixed species eucalypt forest in West Central Victoria, overwood basal areas above 11 m^2/ha have a serious impact on the establishment of seedling regeneration, and favour those shade tolerant species with persistent lignotubers (Kellas *et al.* 1988). Above about 15 m^2/ha even combined stockings of both seedling and lignotuber regeneration is often unsatisfactory. In a study of overwood effects in *E. tricarpa* (red ironbark), Lutze (1998) found that seedling height at age 9 years in plots which had overwood removed at the time of planting was approximately three times that measured in plots with overwood retained. Similarly, for a high elevation mixed species eucalypt forest at Big Ben, North East Region of Victoria, Ryan *et al.* (in prep) found that overwood basal areas >16 m^2/ha inhibited the development of adequate seedling stocking due to high mortality of seedlings. Given the basal area of a 100 cm DBHOB stem is 0.8 m^2, 13 such retained trees/ha will impose these effects.

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[1] P. Dignan, Research Officer, Centre for Forest Tree Technology, Noojee.

For E. delegatensis (alpine ash) in Tasmania, seedling height increment was reduced by between 0.6 and 1.3 cm/yr per m^2 of overwood basal area retained (Battaglia and Wilson 1990). For example, if 10 m^2/ha of stand basal area is retained for 4 years, height increment would be reduced by 24-52 cm. Growth losses increased with decreasing annual rainfall, indicating that competition for soil moisture is an important factor involved.

Silviculture systems research in Victoria (Silvicultural Systems Project) and Tasmania (Arve-31 Demonstration Forest) analysed seedling growth at three years under a variety of overwood levels in both lowland sclerophyll forest and *E. regnans* (mountain ash) forests (Table 3). Growth losses were comparable between all studies, including both height and diameter increment losses. The magnitude of growth loss increased with increasing retained basal area, supporting the theory that zones of influence are additive due to their overlap under higher basal area retention (Incoll 1979).

Table 3. Effect of retained overwood on dominant seedling growth at age 3 years since site preparation, compared with clearfell for: (1) lowland sclerophyll forest, East Gippsland (Faunt *et al.* in prep); (2) *E. regnans* mixed forest, Southern Tasmania (Bassett *et al.* 2000); and (3) *E. regnans* wet sclerophyll forest, Central Highlands (Dignan *et al.* in press).

Retained overwood	Height loss		Volume loss
(proportion of basal area)	(1) mixed species	(2) *E. regnans*	(3) *E. regnans*
10%	13%	16%	15%
30%	55%	na	45%
50%	67%	68%	65%
100%	82%	*74%	96%

Dignan *et al.* (in press) and Bassett *et. al.* (2000) both found that of all growth parameters, stem diameter increment was most affected by competition, contributing to significant early volume loss. For example, Dignan et al. (in press) measured an increase in the height to diameter ratio of *E. regnans* regrowth under overwood, resulting in reduced seedling vigour and low volume production. Bassett *et al.* (2000) noted that suppressed *E. regnan*s seedlings developed a spindly appearance with more widely spaced leaf axils, and larger and fewer leaves. Ashton & Turner (1979) found *E. regnans* to be intolerant of low light conditions, and Ashton & Willis (1982) found that such seedlings did not survive beyond 10 years. In contrast, mixed species seedlings may persist for many years in a suppressed state, developing extensive root and lignotuber systems (Cremer *et al.* 1978; Florence 1996; Ryan 1997).

Canopy cover is another means of describing competition. Florence (1996) presented data relating the percentage overwood canopy cover to the number and diameter of dominant regrowth stems in a stand of *E. fastigata*. He recorded that the percentage of dominants within regrowth remained constant across a range of canopy covers. Therefore changes in the dominant regrowth strata will reflect stocking changes across all regrowth strata. The data presented in Table 4 illustrate the effect of overwood canopy on stocking in terms of basal area. Potential sawlog volume, which is largely a function of basal area and height, will therefore be progressively reduced along a continuum of increasing canopy.

Table 4. Overwood projected canopy cover and the suppressive effect on regrowth basal area (data derived from Florence 1996, p. 202).

	Dominant regrowth stems (of sawlog value)			
Overwood canopy cover	No. of stems/ha	Average diameter (cm)	Basal area (m^2/ha)	Basal area change
0 %	153	51	31	
17-23 %	111	56	27	-13%
47 %	53	56	13	-58%

Clumping of retained trees

Clumping retained overwood may have benefits, including more effective use of habitat trees (Loyn 1985, Lindenmayer 1996, 1997). The impact of overwood on regeneration and regrowth may be reduced by clumping retained trees, effectively reducing the spread of zone of influence. Bi & Jurskis (1997) demonstrated this effect in *E. fastigata* when study trees where clumped with neighbouring regrowth on one side only. However, in drier forest types where competition for soil moisture is high this may not be a factor. Opie (1969), in studying competition in a natural stand of *E. camaldulensis* regrowth at Barmah, states that "the distance aspect of spatial distribution is of little importance." Opie speculated that the root systems are so opportunistically aggressive as to negate much of the supposed effect. In large clumps the effect may hold true, but retention of these may be difficult to apply due to the impact on silvicultural system specifications. In addition, clumping may not suit all fauna groups or species. For example, Gibbons and Lindenmayer (1996) suggest that clumping habitat trees is not necessarily appropriate for arboreal wildlife.

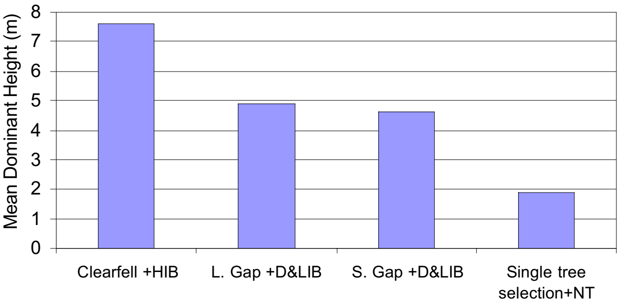
Edge effects

The impact on regrowth by mature edge trees has been widely studied in Australia by analysing seedling growth within a continuum of harvested areas of decreasing gap size. All studies have demonstrated that the forested edge-effect of gaps on eucalypt regeneration can cause significant reductions in early height growth and vigour (King *et al.* 1997; Dignan *et al.* in press; Breidahl and Hewett 1995, Bradshaw 1992, Ashton and Turner 1979) and increases in seedling mortality (Ashton & Willis 1982; Strachan and King 1992, Faunt *et al.* in prep.; Bassett *et al.* 2000.).

For example, Faunt *et al.* (in prep.) found that mean dominant height of the tallest seedlings measured at age 3 years increased with increasing distance from coupe edge in lowland mixed forest. Similarly, seedling stem volume at age 4 years was reduced in E regnans as gap size decreased from 2 ha to single tree selection (Figure 1). Stocking at high basal areas in the latter study resulted in marginal stocking based on current survey standards (Squire et. al. 1991; Forestry Tasmania 1996; NRE 1997).

The above mentioned studies indicate that a suppressive effect from edge trees on young eucalypt regrowth could extend into a coupe up to 70 m. The effect would be expected to reduce as the regrowth increased in size over time, or if adjacent forest was later harvested, removing the forested edge. Linear reservations are also considered a forested edge, further increasing edge effect on a coupe.

Figure 1. Mean dominant height of Eucalyptus regnans seedling regeneration at age 4 years in coupes of decreasing gap size at the Arve-31 Demonstration Forest, Southern Tasmania. Large gap = 0.7 ha; small gap = 0.25 ha; HIB = high intensity slash-burn; LIB = locally intense slash-burn; and NT = soil disturbance (D) during harvesting (Bassett *et al*. 2000.)



An example of the effects of overwood retention

The above discussion is perhaps better demonstrated using an example. Consider a forest carrying five 100 cm DBHOB habitat trees per hectare which have an average basal area of 0.8 m^2/ha, and each a crown ratio of 15. The basal area of the stand prior to harvesting (reference basal area, RBA) was 40 m^2/ha. Thus the 5 habitat trees total 10% of RBA. Table 5 illustrates the growth losses (volume) under various conditions for the stand. Note that early removal of overwood from a young regrowth stand is expected to result in their release, with ultimately little effect on volume by sawlog age. However, Table 5 assumes long term retention of retained habitat trees.

Table 5. A comparison of potential volume losses from commercial trees in different stands due to the presence of 5 habitat trees/ha; each of 100 cm dbhob. Different impacts on stand productivity will result, calculated using results from various studies.

Treatment	Growth loss
1. Mixed age, stocking 40 m^2/ha.	10 %
2. Thinned to 25 m^2/ha.	16 %
3. Regrowth, 40 m^2/ha @ 40 years.	39 % (Incoll 1979)
4. Regrowth, 40 m^2/ha.@ 40 years	17 % (Rotheram 1983)
5. Seedling regeneration	15 %

The growth losses in treatments 1 and 2 are calculated assuming that the unproductive stems have the same competitive status as the crop trees. The estimates of growth loss for treatments 3 and 4 are made from Incoll and Rotheram's work, respectively, assuming a crown to diameter ratio of 15. The final three examples (i.e. treatments 3, 4 and 5) relate to unproductive overwood.

Sustainability targets and conservation values

It is clear in the previous example that overwood has an impact on growth of the remainder of the stand far in excess of that estimated by calculating the proportion of stand stocking occupied by the overwood. Given sustainability targets are based on the projected growth of regrowth and trees of assumed commercial value, it is clear that this issue of unproductive overwood retention is closely related and should be considered in the process of setting sustainability targets. In addition, we have a duty of care to maintain the ecosystem health and integrity of harvested areas, and the suitability of habitat for wildlife requires careful consideration. The challenge for forest management will be to balance the competing objectives of wood production and conservation to achieve socially accepted outcomes, although how much loss of wood production should be accepted and built into sustainability targets remains a challenge requiring immediate attention and resolution.

Conclusions

1. Dominant overwood eucalypts retained beyond harvesting for a long term will impose a suppressive zone of influence on the regenerating stand. It can be expected that the average radius of this zone will be at least 1.7 to 3.0 crown radii around each tree, depending on the vigour of the tree and the availability of site resources.

2. The proportion of area affected will depend on the number of trees retained. For example, retaining 5 to 10 trees/ha with an average crown radius of 7 m, and assuming a zone of radius of 1.7 x 7, will impose a suppressive effect on 25% to 50% of harvested area.

3. Depending on the stocking of retained overwood stems, zones of influence may overlap. For up to 5 trees/ha, the suppressive effects will be approximately additive.

4. Suppressive effects on regrowth include height loss, diameter and volume loss, and a reduction in stocking (stems/ha), leading to a potential under-stocking. Height growth losses of between 13% to 82% have been recorded, depending on the level of overwood, compared to the known height potential of the site with no overwood competition.

5. Clearfelling (with no overwood retention) has been demonstrated to produce the most productive regrowth following harvesting of eucalypt forest. Growth of regenerating ash species will be seriously compromised under a retained canopy of more than 30% of original basal area.

6. Mixed species (non-ash type) are more tolerant and may persist under an overwood canopy until released by gap creation. But loss of stocking and potential volume growth, however, can still be significant up to the time of release.

7. Forested edges, including coupe edges and edges of linear reserves, will also impose a suppressive effect on neighbouring regeneration. Edge effect will become more significant as coupe size is reduced. For gaps (coupes) at or below 2 ha, height and volume losses have been demonstrated to be significant, and the affected area extends up to 70 m from the edge.

8. Sustainability targets are likely to be influenced by retained overwood.

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References

Applegate, G.B., Gilmour, D.A. and Mohns, B. (1988). The use of biomass estimations in the management of forests for fuelwood and fodder production. *Commonwealth Forestry Review* **67**(2): 141-48.

Ashton, D.H. (1975). The seasonal growth of *Eucalyptus regnans* F, Muell. *Australian Journal of Botany* **23;** 239-252.

Ashton, D.H. (1976). The development of even-aged stands in Eucalyptus regnans F. Muell. in Central Victoria. *Australian Journal of Botany* **24**; 397-414.

Ashton, D.H. and Turner, J.S. (1979). Studies on the light compensation point of *Eucalyptus regnans F. Muell. Australian Journal of Botany* 27: 509-607.

Ashton, D.H. and Willis, E.J. (1982). Antagonisms in the regeneration of Eucalyptus regnans in the mature forest. In Newman, E. I. (ed.) *The Plant Community as a Working Mechanism*, pp. 113-128. British Ecological Society. Blackwell Scientific Publications, Oxford.

Attiwill, P.M. and Leeper, G.W. (1987). *Forest Soils and Nutrient Cycles*. Melbourne University Press.

Bassett, O.D. (1996). Seed Crop Assessment Kit - lowland sclerophyll forest. Department of Natural Resources & Environment, Victoria (unpublished).

Bassett, O.D. and White, M.D. (1993). Seed Supply II: Development and testing of seed crop assessment models for three lowland sclerophyll forest eucalypts from East Gippsland. VSP Internal Report 19, Department of Conservation and Natural Resources, Victoria.

Bassett, O.D., Edwards, L.G, Plumpton, B.J (2000). A comparison of four-year-old regeneration following six silvicultural treatments in a wet eucalypt forest in Southern Tasmania. *TasForests* **12:** 35-54.

Battaglia M. and Wilson L.P. (1990). Effects of shelterwood in stocking and growth of regeneration in dry high altitude *Eucalyptus delegatensis* forests. *Australian Forestry* **53** (4): 259-265

Bi, H. and Jurskis, V. (1997). Crown radius and zone of influence of oldgrowth trees in regrowth eucalypt forests. Paper presented to the Research Working Group 4 (Native Forest Silviculture) in Hobart, 11-13 March 1997.

Bradshaw, F. J. (1992). Quantifying edge effect and patch size for multiple use silviculture - a discussion paper. *Forest Ecology and Management* **48**: 249-264.

Breidahl, R. and Hewett, P. J. (1995). A review of silvicultural research in the karri (*Eucalyptus diversicolor*) forest. CALM Science **2** (1): 51-100.

Campbell, R. G. and Bray, P. L. (1987). Regeneration of mountain ash following clearfell of a regrowth stand. Research Branch Report 327. Conservation, Forests and Lands, Victoria.

Campbell, R., McCormick, M., Harrison, M., King, M. And Fitzgerald, T. (1990). Monitoring, evaluation and development of seed supply for alternative silvicultural systems. SSP Internal Progress Report No. 1, Department of Conservation and Environment, Victoria (unpubl.).

Cremer, K.W., Cromer, R.N. and Florence, R. G. (1978). Stand Establishment. In: Hillis, W.E. and Brown, A.G. (eds) *Eucalypts for Wood Production*. CSIRO.

Curtin R.A. (1964). Stand density and the relationship of crown width to diameter and height in *Eucalyptus obliqua*. *Australian Forestry* **28**: 91-105

Daniel, T.W., Helms, J.A. and Baker, F.S. (1979). *Principles of Silviculture 2nd Edition* McGraw-Hill, Inc. pp 317-327

Dexter, B. (1967). *Flooding and regeneration of river red gum*. Bulletin No. 20, Forests Commission, Victoria.

Dexter, B. (1978). Silviculture of the river red gum forests of the Central Murray flood plain. *Proceedings of the Royal Society Victoria* **90:** 175-92.

Dignan, P., King, M., Saveneh, A. And Walters, M. (in press). The regeneration of *Eucalyptus regnans* f. Muell. under alternative silvicultural systems: seedling growth and density under retained overwood. *Forest Ecology and Management*.

Faunt, K.A., Geary, P.W., Cunningham, R.B. and Gibbons, P. (in prep). Silvicultural Systems Project: Germination and early survival of eucalypt regeneration following a range of harvesting and site preparation treatments in a lowland sclerophyll forest. Department of Natural Resources & Environment.

Florence, R. G. (1996). *Ecology and Silviculture of Eucalypt Forests*. CSIRO, Australia.

Forestry Tasmania (1996). *Regeneration Surveys and Stocking Standards*. Native Forest Silviculture, Technical Bulletin No. 6 (revised version). Forestry Tasmania, Tasmania.

Gibbons, P. and Lindenmayer, D.B. (1996). Issues associated with the retention of hollow-bearing trees with eucalypt forests managed for wood production. *Forest Ecology and Management* **83**: 245-79.

Gibbons, P. and Lindenmayer, D.B. (1997). Forest Issues 2: Hollow dependent fauna in timber production forests. In *Environmental Heritage Monograph Series 3*. NSW Parks and Wildlife Service

Incoll, W.D. (1979). Effects of overwood trees on growth of young stands of *Eucalyptus sieberi*. *Australian Forestry* **42** (2):110-116.

Kellas, J.D., Owen, J.V., and Squire, R.O. (1982). *Response of Eucalyptus sideroxylon to release from competition in an irregular stand*. Forestry Technical Papers No. 29, Forests Commission Victoria.

Kellas, J.D., Edgar, J.G., and Squire, R.O. (1987). Response of messmate stringybark regrowth to release in irregular stands of mixed eucalypts. *Australian Forestry* **50** (4):253-259.

Kellas, J.D., Edgar, J.G., and Squire, R.O. (1987). Response of messmate stringybark regrowth to release in irregular stands of mixed eucalypts. *Australian Forestry* **50** (4):253-259.

Kellas, J.D., Jarrett, R.G., and Morgan, B.J.T. (1988). Changes in species composition following recent shelterwood cutting in mixed eucalypt stands in the Wombat Forest, Victoria. *Australian Forestry* **51** (2):112-118.

Kellas, J.D., Oswin, D.A., and Ashton, A.K. (1996). Growth of red ironbark between 1972 and 1995 on research plots in the Heathcote Forest. Report to the Forests Service (unpubl).

King, M., Rab, A. and Baker, T. (1993). The regeneration of *Eucalyptus regnans* under alternative silvicultural systems 5: Effect of seedbed on seedling growth. VSP Internal Report No. 24. Conservation and Natural Resources, Victoria.

King, M., Dignan, P., Campbell, R., Walters, M. And Strachan, K. (1977). *Eucalyptus regnans* regeneration ecology. In Campbell, R. (Ed), *Evaluation and development of sustainable silvicultural systems for multiple purpose management of mountain ash forests*. VSP Technical Report No. 27. Centre for Forest Tree Technology, Department of Conservation and Natural Resources, Victoria.

Lindenmayer, D. (1996). *Wildlife and Woodchips. Leadbeaters Possum, A Test Case for Sustainable Forestry*. The Australian National University - UNSW Press.

Lindenmayer, D. (1997). Differences in the biology and ecology of arboreal marsupials in forests of South-eastern Australia. *Journal of Mammalogy* **78**(4): 1117-27.

Lockett, E.J. and Candy, S.G. (1984). Growth of eucalypt regeneration established with and without slash-burns in Tasmania. *Australian Forestry* **47**(2): 119-25.

Loyn, R.H. (1985). Strategies for conserving wildlife in commercially productive eucalypt forest. *Australian Forestry* **48**(2): 95-101.

Lutze, M. (1998). Establishment of *E. tricarpa* (red ironbark) from planted seedlings in the lowland forests of East Gippsland. Research Report 361, Forests Service, Department of Natural Resources and Environment, Victoria (unpubl.)

NRE (1996). *Code of Forest Practices for Timber Production* (Revision No. 2). Department of Natural Resources and Environment, Victoria.

NRE (1997). *Eucalypt Stocking Surveys*. Native Forest Silviculture Guideline No. 10. Forests Service, Natural Resources and Environment, Victoria.

Opie, J.E. (1968). Predictability of individual tree growth using various definitions of competing basal area. *Forest Science* **14** (3):314-323.

Opie, J.E. (1969). *The individual tree as a sampling unit*. Ph. D. Thesis, School of Forestry, Melbourne University, Australia.

Raison, R. J., Jacobson, K.L., Connell, M.J., Khanna, P.K., Bauhus, J., Falkiner, R.A., Smith, S.J., Piotrowski, P. and Keith, H. (1991) Project 1. Nutrient cycling and tree nutrition. In CSIRO (1991). Collaborative Silvicultural Systems Research in East Gippsland Between CSIRO and the Department of Conservation and Environment. Interim Report.

Raven, P.H., Evert, R.F. and Curtis, H. (1981) *Biology of Plants*. (3rd edition). Worth Publishers, New York.

Rotheram, I. (1983). Suppression of growth of surrounding regeneration by veteran trees of karri (*Eucalyptus diversicolor). Australian Forestry* **46** (1): 8-13.

Ryan, M.F. (1997). Silviculture guideline for the mixed species forests of the North East Area. NEMSS Report No. 6, Department of Natural Resources and Environment, Victoria. (unpubl.)

Ryan, M.F., Dore, D., and Bassett, O.D. (in prep). *Studies in aspects of silviculture in the forests of the North East Region, Victoria*. NEMSS Report No. 5. Department of Natural Resources and Environment, Victoria. (unpubl.)

Strachan, K. and King, M. (1992). *The regeneration of Eucalyptus regnans under alternative silvicultural systems. 3. Germination and early survival.* (A progress report on the first seasonal replicate). VSP Internal Report No. 10. Conservation and Environment, Victoria.

Squire, R.O., Dexter, B.D., Eddy, A.R., Fagg, P.C., and Campbell, R.G. (1991). *Regeneration silviculture for Victoria's eucalypt forests*. Silvicultural Systems Project (SSP) Technical Report No. 6. Department of Conservation and Environment, Victoria.