BRANCH OCCLUSION AFTER PRUNING IN FOUR CONTRASTING SUB-TROPICAL EUCALYPT SPECIES

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SMITH, R. G. B., DINGLE, J., KEARNEY, D. & MONTAGU, K. 2006. Branch occlusion after pruning in four contrasting sub-tropical eucalypt species. Branch related defects are the major cause of degrade in eucalypts grown for solid wood. The effects of pruning on the growth and branch occlusion in *Eucalyptus cloeziana, E. pilularis, E. dunnii* and *E. grandis* were studied. Trees of each species were pruned to remove 30% of the green crown at 3.5 years of age. Diameters and the state of all branches in two 0.5 m sections of trunk were assessed at one, two and four years after pruning. Growth rates were unaffected two years after pruning in all species. In all species, except *E. cloeziana,* the rate of occlusion of dead branches was not significantly different between pruned and unpruned branches. In contrast, the greatest difference in occlusion rates was between pruned and unpruned live branches. *Eucalyptus grandis* and *E. dunnii* showed high early rates of occlusion compared with *E. pilularis* and *E. cloeziana* for the first year. The occlusion rates of unpruned branches generally showed a positive correlation between branch size and time to occlusion. Relationships were more complex in species that self-pruned less efficiently. Since occlusion rates in dead branches (pruned and unpruned) were similar, there would be little benefit in pruning dead branches and it may increase susceptibility to decay entry and the occurrence of loose knots. Pruning only green branches may be difficult in efficient self-pruning species.

Keywords: Crown dynamics, self-pruning, wood quality, solid wood production

SMITH, R. G. B., DINGLE, J., KEARNEY, D. & MONTAGU, K. 2006. Taupan dahan selepas pemangkasan dalam empat spesies *Eucalyptus* subtropika yang berlainan. Kecacatan dahan merupakan penyebab utama kemerosotan *Eucalyptus* yang ditanam untuk kayu padu. Kesan pemangkasan terhadap pertumbuhan dan taupan dahan *E. cloeziana, E. pilularis, E. dunnii* dan *E. grandis* dikaji. Pokok berumur 3.5 tahun dipangkas 30% daripada silara hijaunya. Semua dahan pada dua bahagian batang pokok yang berukuran 0.5 m direkod diameternya dan dinilai keadaannya pada satu, dua dan empat tahun selepas pemangkasan. Kadar pertumbuhan bagi semua spesies tidak berubah untuk dua tahun selepas pemangkasan. Untuk dahan mati, kadar taupan bagi dahan yang dipangkas tidak berbeza dengan ketaranya daripada dahan yang tidak dipangkas. Ini diperhatikan dalam semua spesies kecuali *E. cloeziana.* Sebaliknya, kadar taupan paling ketara antara dahan hidup yang dipangkas dengan dahan hidup yang tidak dipangkas. *Eucalyptus grandis* dan *E. dunnii* menunjukkan kadar taupan yang lebih tinggi daripada *E. pilularis* dan *E. cloeziana* untuk tahun pertama. Kadar taupan dahan tak pangkas secara amnya menunjukkan korelasi positif antara saiz dahan dengan masa taupan. Hubungan adalah lebih kompleks dalam spesies yang pemangkasan sendirinya kurang efisien. Oleh sebab kadar taupan dalam dahan mati (pangkas dan tak pangkas) adalah sama, memangkas dahan mati tidaklah berfaedah. Pemangkasan mungkin meningkatkan kerentanan terhadap jangkitan dan menggalakkan kejadian buku gegai. Pemangkasan dahan hijau mungkin susah dalam spesies yang pemangkasan sendirinya efisien.

INTRODUCTION

There is increasing interest around the world in growing plantation eucalypts for solid wood production to replace decreasing supplies of wood from natural forests. This represents a major change in management focus from the production of pulpwood. There are also major differences in possible markets from traditional plantation species due to the dominance of pine in structural markets. Appearance grade products will be important because of the high value they attract.

The wood quality parameters of greatest

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importance for solid wood production are quite different from those for pulpwood (Montagu *et al.* 2003). Several sawing studies have shown that the major factor limiting grade recovery is knots and knot related defects (Waugh & Yang 1994, Waugh 1996, Yang & Waugh 1996a, Yang & Waugh 1996b, Washusen *et al.* 1998, Leggate *et al.* 2000). Pruning is the main management technique available to restrict the knotty core and therefore reliably maximize the production of clear wood within the log. However, while a great deal is known about canopy dynamics of some temperate eucalypts (Gerrand *et al.* 1997, Pinkard & Beadle 1998a, Pinkard & Beadle 1998b, Pinkard *et al.* 1999), little is known about the canopy dynamics of sub-tropical eucalypt species in response to pruning (Montagu *et al.* 2003).

The timing of pruning is important in relation to canopy closure. Pruning too great a percentage of the canopy volume before canopy closure will significantly reduce growth. Some species have been observed to self-prune efficiently making management and timing of pruning difficult and perhaps unnecessary (Maree 1979). Other species are not so efficient, making pruning essential to control knot formation within wood (Gerrand *et al.* 1997). There is also evidence that some (temperate) species do not eject branch stubs efficiently and that pruning may be associated with disease entry and rot (Gerrand *et al.* 1997, Wardlaw & Neilsen 1999, Mohamed *et al.* 2000, Montagu *et al.* 2003). A basic process is the ability of branches to senesce and the occlusion of branch stubs.

This trial assessed branch occlusion with and without pruning in *Eucalytus pilularis, E. grandis, E. cloeziana* and *E. dunnii.* The growth response after pruning, the occlusion rates of pruned and unpruned trees and the effect of branch size on occlusion rates were assessed.

MATERIALS AND METHODS

The experiment was undertaken in two plantations approximately 5 km apart in northern New South Wales (latitude 28° 44', longitude 153° 20'). Both plantations were established in March 1994 at an initial stocking of 1000 stems per hectare. *Eucalyptus cloeziana* and *E. pilularis* were planted at Byrill Creek, and *E. dunnii, E. grandis* and *E. pilularis* were planted at Mebbin. The rows were spaced 4 m apart and trees were planted at 2.5 m spacing along the rows. Byrill Creek and Mebbin are both high quality sites. Mean annual rainfall at Tyalgum (approximately 5 km north) is 1555 mm. The altitude of both sites is approximately 250 m asl. The soils of both sites are typically well drained and more than 1 m deep, with clay loam topsoils overlying light to medium clay subsoil.

For each species 20 trees were selected as suitable for pruning using form criteria. Trees that had forks, sweep or large numbers of branches were rejected. Trees without eight surrounding buffer trees were also rejected. Pruning treatments (30% of the green crown height) were applied to half the trees (selected at random) when the trees were approximately 3.5 years old. Green crown length was defined as the total height minus the height to the lowest live branch that was a contiguous part of the crown. Therefore the length of the crown removed and the height pruned varied for each tree. Contractors using shears carried out the pruning. Details of the selected trees are given in Table 1.

Measurements were undertaken prior to pruning and at 1, 2 and 4 years post pruning. All branches from 1.5 to 2 m, and from 3.5 to 4.0 m were mapped and measured on each tree and the branch diameter and status [live, dead (complete branch), stub or hole (incomplete branch) or occluded] were recorded. Branch diameter was measured approximately 3 cm from the trunk junction past any swelling at the branch base. The periodic annual diameter increment of each tree was calculated for each of the time period and the data was analysed using ANOVA. The effects of pruned or unpruned and branches being live or dead were assessed using the proportion of branches occluded per tree as the response in GLM in Splus. Each species and time after pruning was analysed separately. For unpruned branches the effects of initial branch size (1–5, 6–10, 11–15, 16–20, > 20mm diameter) and status (live or dead) on time to occlusion (1, 2, 4, > 4 years after pruning) were assessed using the count of branches in a three way contingency table analysis.

Table 1 Mean tree and crown dimensions of sample trees

Species	Site	Treatment	Mean dbh (cm)	Total tree height (m)	Green crown height (m)	Pruned height (m)
Eucalyptus cloeziana	Byrril Ck	Pruned	10.3 ± 1.1	9.3 ± 0.6	2.7 ± 1.0	4.6
		Unpruned	10.4 ± 1.2	9.1 ± 0.9	2.4 ± 0.5	
Eucalyptus pilularis	Byrril Ck	Pruned	13.3 ± 1.1	11.7 ± 0.6	3.9 ± 0.9	6.3
		Unpruned	12.7 ± 1.2	11.6 ± 0.5	3.8 ± 1.0	
	Mebbin	Pruned	11.7 ± 1.1	11.1 ± 0.7	3.8 ± 0.9	6.0
		Unpruned	12.1 ± 1.3	11.3 ± 0.6	3.3 ± 0.8	
Eucalyptus dunnii	Mebbin	Pruned	13.0 ± 1.1	10.9 ± 0.8	2.3 ± 1.0	4.9
		Unpruned	12.8 ± 1.8	11.2 ± 1.0	2.4 ± 0.8	
Eucalyptus grandis	Mebbin	Pruned	12.3 ± 1.3	12.3 ± 0.7	3.6 ± 1.2	6.2
		Unpruned	12.8 ± 1.4	12.3 ± 1.2	3.9 ± 1.0	

RESULTS

Tree growth response

There was no significant difference in stem growth between pruned and unpruned trees at any time after pruning (Figure 1), with the exception of *E. dunnii*, where growth was reduced in the first year after pruning only ($F_{1,18} = 8.77$, $p < 0.01$). Periodic annual increments were not significantly different in later measurements.

Branch state at the time of pruning

Considerable species difference in the frequency and status of branches prior to pruning were observed (Table 2). *Eucalyptus grandis* and *E. pilularis* (Byrill) had low numbers of live branches in both stem sections. Higher numbers of retained live branches occurred in *E. dunnii* and *E. cloeziana*. *Eucalyptus grandis* had the highest percentage of branches that had already started the occlusion process and *E. pilularis* had the highest proportion of dead branches in each section.

Branch occlusion processes

Some characteristics of the occlusion patterns were common among the species. Occlusion rates were not significantly different between pruned and unpruned dead branches of all species, except for *E. cloeziana* (Figure 2). In contrast, the greatest difference in occlusion rates was between pruned and unpruned live branches. The most rapid rates of occlusion were in pruned live branches and the lowest rates were in unpruned live branches. The contrasted occlusion behaviours of live and dead branches caused a significant interaction between pruned and branch status in all species. This occurred after 12 months in *E. grandis* ($X^2_{1,32}$ $p < 0.001$) and *E. pilularis* ($X^2_{1,57}$ $p < 0.005$) and after 24 months in *E. cloeziana* ($F_{1,32}$ $p < 0.05$) and *E. dunnii* ($X^2_{1,34}$ $p < 0.05$). Pruned branches occluded significantly faster than unpruned for all species at all times.

Some characteristics of the patterns of occlusion were different between species (Figure 2). The greatest proportion of *E. dunnii* and *E. grandis* branches occluded during the first year and a smaller proportion during the second and subsequent years after pruning. In contrast only a small proportion of *E. pilularis* and *E. cloeziana* branches occluded during the first year, followed by a large proportion during the second year.

Branch size and time to occlusion

For all species, except *E. dunnii,* the diameter of branches was significantly related to time to occlusion (Figure 3, *E. pilularis* $X^2_{12,15}$ $p < 0.005$; *E. grandis* $X^2_{12,15}$ $p < 0.00005$; *E. cloeziana* $X^2_{12,15}$ $p < 0.00001$). Larger diameter branches generally took longer to occlude.

DISCUSSION

Tree growth response

Tree growth rates were generally not affected by the removal of 30% of green crown, except a short-term reduction in growth in *E. dunnii.* This confirms that the pruning treatments were below

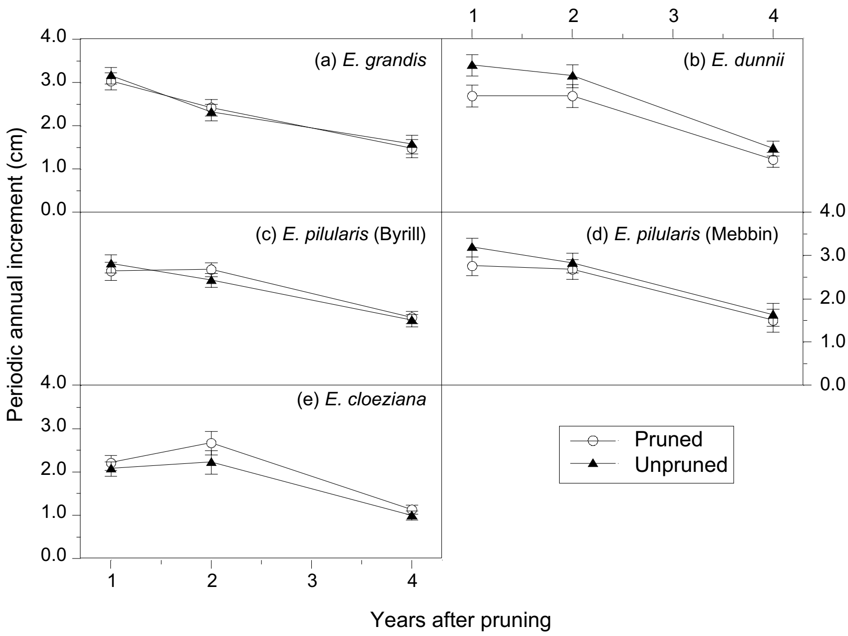

Figure 1 The periodic annual diameter increment of *E. grandis, E. dunnii, E. pilularis* and *E. cloeziana* for pruned and unpruned trees over four years after pruning. Error bars are standard errors.

Table 2 The number and average diameter of branches that were live, dead or no longer a complete branch at time of pruning

Site	Species	Ht section (m)	Complete branches				Not complete branches	
			Dead		Live			
			n	DOB (mm)	n	DOB (mm)	n	DOB (mm)
Byrill Ck	*E. cloeziana*	1.5–2.0	112	8.3 ± 3.6	19	18.1 ± 3.8	16	2.8 ± 1.3
		3.5–4.0	84	7.1 ± 2.6	39	15.4 ± 4.9	4	4.8 ± 1.3
	E. pilularis	1.5–2.0	120	10.0 ± 4.8	1	20.0 ±	12	6.7 ± 4.3
		3.5–4.0	88	9.8 ± 4.1	13	21.0 ± 5.1	4	3.8 ± 1.0
Mebbin	*E. dunnii*	1.5–2.0	104	7.1 ± 3.7	29	18.9 ± 6.2	44	4.9 ± 2.9
		3.5–4.0	60	7.0 ± 4.1	33	17.3 ± 6.2	18	3.6 ± 1.9
	E. grandis	1.5–2.0	105	8.6 ± 4.6	1	28.0 ±	53	6.3 ± 5.0
		3.5–4.0	58	8.9 ± 5.9	19	24.1 ± 5.6	25	4.6 ± 2.5
	E. pilularis	1.5–2.0	137	9.1 ± 3.3	9	19.3 ± 2.2	5	5.4 ± 2.3
		3.5–4.0	61	9.4 ± 3.6	42	16.3 ± 3.8	2	4.0 ± 0.0

DOB = diameter of branches

the range expected to reduce growth (40–50% of green crown removal) (Pinkard & Beadle 1998a). The reduction in growth in *E. dunnii* suggests that growth may be affected if a more severe pruning or several pruning lifts were undertaken. There may be a disadvantage from lower growth rates caused by pruning affecting occlusion rates. It is not clear from this study how different growth rates affect occlusion for a particular species, but faster growing species (*E. grandis* and *E. dunnii*) had greater crown depths and higher early occlusion rates and the slowest growing species had the shortest crown depths and the lowest occlusion rate (Figure 2). The pattern of periodic diameter increment for *E. pilularis* and *E. cloeziana* was not greatly different from *E. grandis* and *E. dunnii,* suggesting diameter growth is not primarily responsible for the different patterns of occlusion. The lack of a great difference between *E. pilularis* at Byrill and at Mebbin suggests that site is not strongly influencing the occlusion rates.

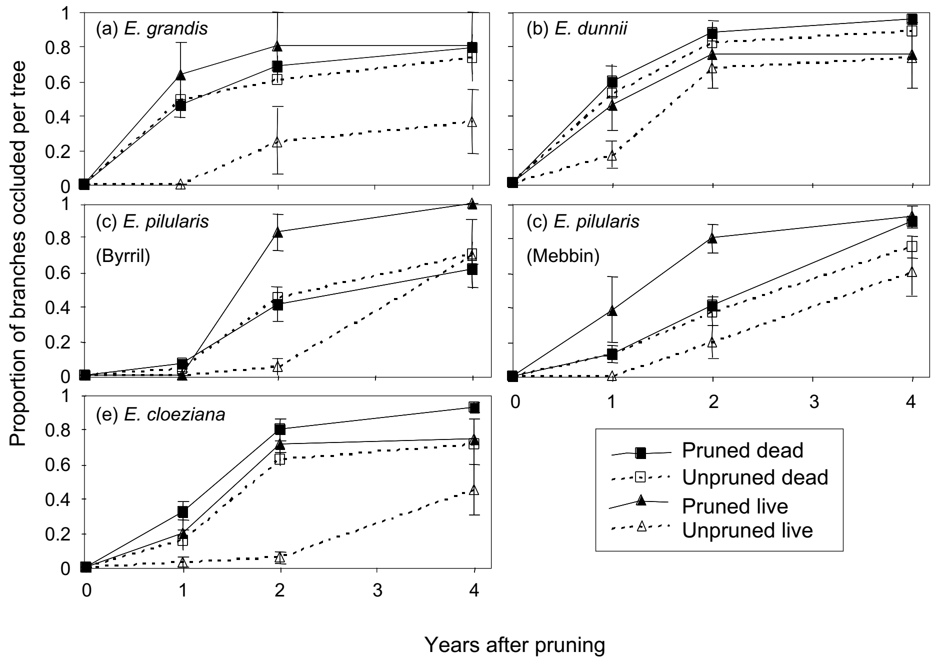

Figure 2 The proportion of live, dead, pruned and unpruned branches per tree occluded over time for each species. Error bars are standard errors.

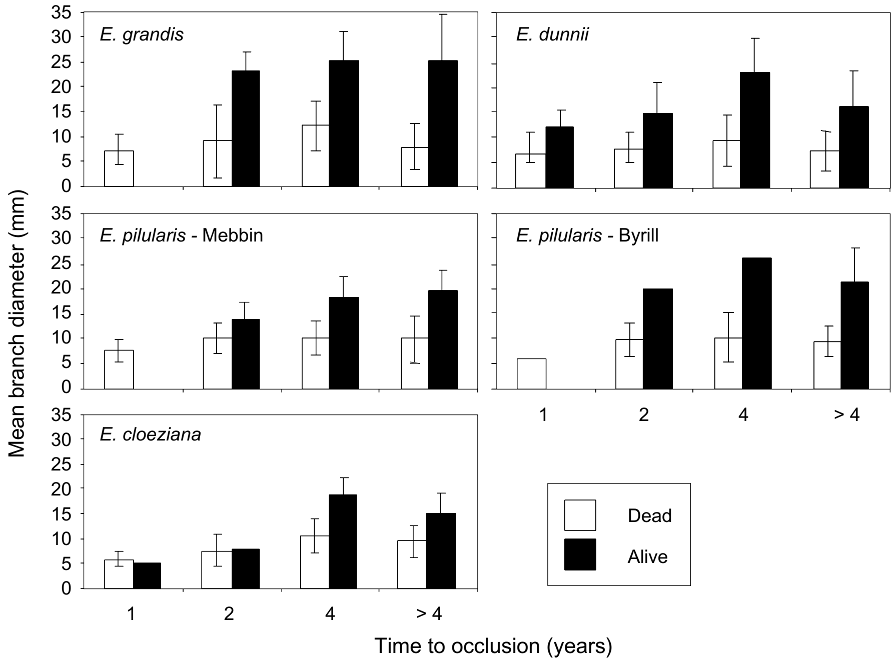

Figure 3 Average diameter of the unpruned branches that occluded at each measurement for *E. grandis, E. dunnii, E. pilularis* and *E. cloeziana*. Error bars are standard deviations.

Branch occlusion processes

The similar occlusion rates of pruned and unpruned dead branches suggest that these species are highly efficient at self-pruning. Once the green crown has risen, dead branches are not retained. Pruning dead branches, therefore, offers no benefit because branches occlude at similar rates whether they are pruned or not. Pruning dead branches can create dead knots (Maree 1979), and inefficient branch stub ejection may create problems of kino traces through the log (Gerrand *et al.* 1977). Dead pruned branch stubs may also provide a disease entry point. In a small number of cases, branch scars had kino exudates after previously being recorded as occluded. However, a further inspection revealed that this was only temporary. Destructive sampling is required to determine the relationships between pruning, decay or disease entry and the effect on wood quality within trees.

There were differences in response to pruning and self-pruning behaviour between the four species. *Eucalyptus grandis* and *E. dunnii* branches occluded more rapidly during the first year than *E. cloeziana* and *E. pilularis.* This division between species corresponds to that noted by Noble (1989) between the *Eucalyptus* subgenera *Symphomyrtus* and *Monocalyptus.* The major difference between species was high percentages of branches occlude early in *E. grandis* and *E. dunnii* compared with *E. pilularis* and *E. cloeziana.* However, after two years the difference in occlusion rates between pruned and unpruned live branches was greater than that between species.

The difference in occlusion rate between species will be important if thinning is undertaken. Thinning after pruning would increase the tendency for branches above pruned height to remain alive and slow the rise of the green crown. This trend could be assumed to be greatest in *E. cloeziana* and less marked in *E. pilularis, E. grandis* and *E. dunnii.*

Responses to spacing and thinning are also important characteristics for management in the formulation of pruning and thinning schedules. Heavy thinning and wider spacing can also increase the incidence of larger (and more persistent) branches and therefore branch related defects (Kearney 1999, Neilsen & Gerrand 1999, Montagu *et al.* 2003). However, the effect will depend on the timing of thinning and the initial spacing. The initial spacing in this study was at the lower end of the range that appears important in influencing crown dynamics (Schonau 1974, Jenkin 1990, Kearney 1999, Nielsen & Gerrand 1999, Montagu *et al.* 2003).

If it is accepted that pruning must take place while branches are alive, timing of pruning is a balance between pruning before crown rise and not removing too much crown so as to reduce growth. The rate of crown rise in *E. grandis* is rapid and approximately equal to height growth (Maree 1979, Klootwijk 2001). The results of this study confirm observation of stands on the North Coast of New South Wales that *E. dunnii* is similar to *E. grandis, E. pilularis* is intermediate and *E. cloeziana* slower.

In South Africa, early pruning policies for *E. grandis* advocated careful timing of pruning to ensure only green branches were pruned. This policy was eventually abandoned because it was logistically too difficult due to the rapid rise of the green crown (Maree 1979). The difference between species evident from this study suggests pruning may be necessary in *E. cloeziana* where the crown rises less rapidly. For species that self-prune efficiently, pruning is unlikely to be economic in countries with high labour cost such as Australia.

Branch size and occlusion

Large branches are thought to create problems such as increased risk of disease entry and problems with occlusion processes. Occlusion rate was related to branch size and so smaller branches would occlude faster. However, branch size was also strongly related to whether branches were live or dead at the start of the study, with live branches having large diameters (Table 2). This study under-sampled live pruned branches because sample heights were fixed. The pruning prescription was undertaken at age 3.5 years after the green crowns had begun to rise. A better design would sample a fixed number of live and dead branches from above and below the green crown base on pruned and unpruned trees. Moreover, there were few branches larger than 25 mm which is thought to be critical for occlusion processes (Jacobs 1955).

In contrast to species that self-prune efficiently, where rapid crown rise makes it difficult to schedule pruning, species that hold branches such as *E. cloeziana* can suffer a different problem. Branches above the pruned height gain extra resources and so grow more rapidly and larger than would occur in the absence of pruning. The branches can become very large before a second lift in pruning, which may cause problems with occlusion and disease entry after the second pruning lift (Montagu *et al.* 2003).

Even if pruning is successful branches will develop above the pruned height and devalue the first crown log through degrade due to larger knot size. Similar problems with large branches taking longer to occlude will occur at lower initial densities (Kearney 1999).

Social and economic factors

As well as differences between species and site the question of whether to prune will also depend on many social and economic factors. For example, in Australia where pruning is expensive due to high labour costs it may be more economic to employ an alternative strategy using higher initial stockings and delaying thinning until the crown base is sufficiently high. Although higher stockings and delayed early thinning will reduce early diameter growth, this will be of little consequence for wood quality as the wood being produced is within the knotty core and of low value. Higher initial planting densities will result in smaller branches and more rapid green crown rise (earlier branch death and therefore size), leading to more efficient self-pruning.

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