Regeneration of Blackwood from Ground-stored Seed in the North Arthur Forests, North-western Tasmania

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Abstract

The total quantity of blackwood seeds within a soil profile in the North Arthur Forests was greater than 20 000 per m². Viable seeds were located to a depth of at least 100 cm, with nearly half occurring within the upper 10 cm horizon of the soil profile. Results from experimental treatments indicated that high intensity burning destroyed 67% of the viable seed in the top 7.5 cm of the soil profile and stimulated the germination of more than 95% of the remaining seed. In contrast, soil disturbance resulted in the germination of up to 21% of the seed, with the remainder being retained as a reservoir for future germinations. Burning of logging slash in three blackwood-rich forest coupes resulted in a mosaic of different burning intensities, with high intensity ashbed representing about 8% of the ground area. An acceptable stocking of blackwood was recorded on all types of seedbed. It was concluded that on such sites the current practice of slash burning is unlikely to have a detrimental effect on the overall stocking of seedlings in blackwood regeneration areas.

Introduction

Blackwood (*Acacia melanoxylon*) is a commercially important understorey tree in the wet eucalypt forests of north-western Tasmania. Silvicultural regimes developed for these forests depend upon the regeneration of blackwood from ground-stored seed (Forestry Commission 1991a). Prolific germination of blackwood occurs following logging on seedbeds exposed by logging disturbance or burning. The burning of logging slash is normally undertaken to reduce fuel loads and to prepare an optimum seedbed for the establishment of the eucalypt species (predominantly *Eucalyptus obliqua*). However, high intensity burning that totally consumes the litter and humus layers of the soil is likely to destroy some ground-stored blackwood seed and may therefore restrict the future distribution of blackwood regeneration. This paper reports on investigations into the regeneration of blackwood from ground-stored seed following disturbance and burning treatments within the North Arthur Forests.

Methods

Seed distribution within the soil

The distribution of blackwood seed at various depths within the soil profile was measured at one study site within the Salmon River Forest Block, 30 km south-west of Smithton in the north-west of Tasmania (Figure 1). The forest type was a mosaic containing patches of *E. obliqua* wet forest with a mean dominant height (MDH) of 43 m and patches of blackwood with a MDH of 32 m. Common understorey species included *Nothofagus cunninghamii, Atherosperma moschatum, Dicksonia antarctica, Polystichum proliferum* and *Blechnum nudum*. The soil had an organic horizon 5 cm in depth over a light brown-grey gradational soil derived from Precambrian mudstone. Seven sampling sites were randomly located at least 20 m apart within an area of 0.75 ha. At each site, a soil auger 6 cm in diameter was used to remove

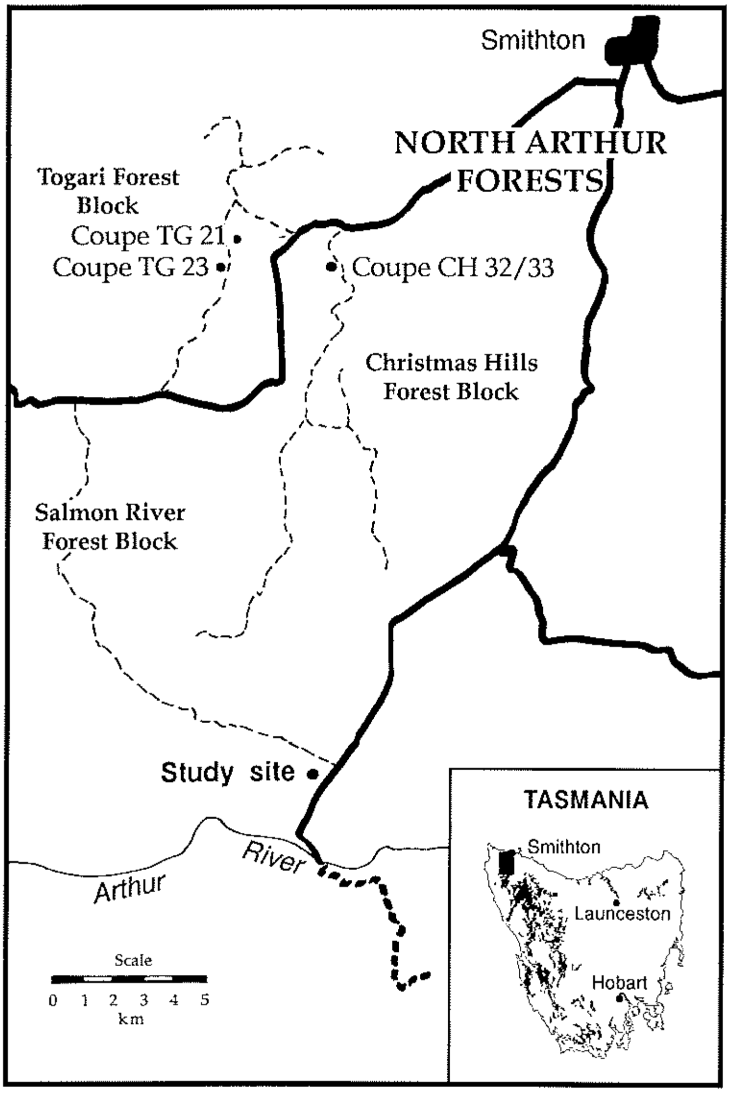


Figure 1. Locality of the study site within the North Arthur Forests.

profile sections at 5 cm intervals to a depth of 100 cm. The sections were then washed and sieved to enable all blackwood seeds to be manually extracted and recorded. Seed viability for each section was determined by conducting germination tests on the extracted seeds.

Effects of soil treatments on germination

The response of ground-stored blackwood seed to various treatments was investigated using soil sections from the study site described above. A uniform area was selected within a stand of mature blackwood trees. Within this area, dry forest fuels were heaped and burnt to create two patches of ashbed that were both approximately 1.5 m x 1.5 m in size. The burns were carried out in late February when the soils were relatively dry (Soil Dryness Index = 87, see Mount 1972) in order to simulate the soil-heating effects likely to occur during a wildfire or slash burn. Soil samples to 7.5 cm in depth were excavated to fit exactly into square plastic pots 16.5 cm x 16.5 cm in surface area. Sixteen samples were collected from the burnt areas and a further 16 samples from the unburnt parts of the study area. Eight of the samples from each of the burnt and unburnt areas were subjected to a 'disturbance' treatment that comprised the removal of litter layers followed by hand mixing of the mineral soil. The remaining samples were very carefully excavated to minimise any disturbance to the litter layer or soil profile.

After excavation, all samples were transferred to a shadehouse in Smithton. Four replicates of each treatment were placed under full light conditions and the remaining four replicates were totally surrounded by shade-cloth to simulate the availability of light under a forest canopy (about 20% transmission). In total, there were 32 samples comprising eight treatments (2 burn x 2 disturbance x 2 light x 4 replicates). The pots were watered regularly and germinants were counted twice per week until germination had virtually ceased, after 12 weeks. The samples were then washed and sieved to recover ungerminated seeds. Germination tests were conducted to determine the viability of these seeds.

Stocking of blackwood following forest regeneration treatments

The stocking of blackwood on various seedbeds was assessed in three forest coupes being managed for blackwood regeneration. The coupes were located in the Togari (TG21 and TG23) and Christmas Hills (CH32/33) Forest Blocks (Figure 1). All coupes were previously covered by wet sclerophyll (*E. obliqua)* forest with deep mudstone soils derived from Cambrian greywacke. Following clearfelling, the coupes were burnt and sown with eucalypt seed. Standard netting fences were erected to reduce, but not totally exclude, browsing by native animals (Forestry Commission 1991a). The stocking of blackwood was expressed as the percentage of plots (4 m^2 in area) containing one or more blackwood seedlings (Forestry Commission 1991b). Surveys were undertaken one or two years after the regeneration treatment. The seedbed occupied by the dominant seedling on the plot (or the seedbed occupying the greatest proportion of unstocked plots) was assessed as follows:

- Hot burn: litter and organic layers consumed, intense soil-heating;
- Medium burn: litter layers consumed, moderate soil-heating;
- Low burn: fine fuels partially consumed, little soil-heating;
- No burn: no soil-heating, low level of logging disturbance to the soil;
- Snig track: no soil-heating, major level of logging disturbance to the soil.

Results

Seed distribution within the soil

Blackwood seed at the study site was found to be distributed within the soil profile to a depth of at least 100 cm (Table 1, Figure 2). The total number of seeds within the profile equated to more than 20 000 seeds per m^2.

Table 1. Total number and viability of seeds distributed at various depths within the soil profile.

Soil depth (cm)	Number of seeds*	Seed viability (%)*
0–5	18.0 ± 4.9	99.0 ± 1.0
5–10	14.6 ± 4.5	98.0 ± 1.2
10–15	6.7 ± 0.7	100.0 ± 0.0
15–20	5.1 ± 0.8	92.0 ± 2.8
20–25	3.6 ± 0.3	90.0 ± 5.3
25–30	2.0 ± 0.3	79.2 ± 16.4
30–40	4.1 ± 1.2	92.4 ± 0.7
40–50	3.9 ± 0.9	100.0 ± 0.0
50–60	3.6 ± 1.0	95.8 ± 4.2
60–70	3.4 ± 1.3	92.1 ± 5.6
70–80	1.7 ± 0.8	88.8 ± 6.6
80–90	1.1 ± 0.6	80.6 ± 10.0
90–100	0.4 ± 0.3	100.0 ± 0.0
Total	68.2 ± 16.2	94.5 ± 1.2

* Mean ± S.E. ($n = 7$)

Table 2. Analysis of variance tables for (a) total number of seeds, (b) total number of viable seeds, (c) total number of germinants and (d) percentage germination of viable seeds. (= Arcsine transformation of % data.)*

(a) Total seeds

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Burning	206 885	1	206 885	9.253	< 0.01
Disturbance	69	1	69	0.003	n.s.
Light	30 074	1	30 074	1.345	n.s.
Burning x disturbance	176	1	176	0.008	n.s.
Burning x light	7 412	1	7 412	0.331	n.s.
Disturbance x light	6 527	1	6 527	0.292	n.s.
Burning x disturbance X light	13 082	1	13 082	0.585	n.s.
RESIDUAL	536 635	24	22 360		
TOTAL (CORRECTED)	800 859	31			

(b) Total viable seeds

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Burning	242 672	1	242 672	10.808	< 0.01
Disturbance	19	1	19	0.001	n.s.
Light	26 068	1	26 068	1.161	n.s.
Burning x disturbance	64	1	64	0.003	n.s.
Burning x light	9 858	1	9 858	0.439	n.s.
Disturbance x light	5 977	1	5 977	0.266	n.s.
Burning x disturbance x light	13 599	1	13 599	0.606	n.s.
RESIDUAL	538 848	24	22 452		
TOTAL (CORRECTED)	837 105	31			

(c) Total germinants

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Burning	29 041	1	29 041	16.296	< 0.001
Disturbance	153	1	153	0.086	n.s.
Light	3 081	1	3 081	1.729	n.s.
Burning x disturbance	685	1	685	0.384	n.s.
Burning x light	8	1	8	0.004	n.s.
Disturbance x light	903	1	903	0.507	n.s.
Burning x disturbance x light	181	1	181	0.101	n.s.
RESIDUAL	42 770	24	1 782		
TOTAL (CORRECTED)	76 821	31			

(d) % germination*

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Burning	9.627	1	9.627	970.852	< 0.001
Disturbance	0.014	1	0.014	1.415	n.s.
Light	0.007	1	0.007	0.725	n.s.
Burning x disturbance	0.045	1	0.045	4.567	< 0.05
Burning x light	0.046	1	0.046	4.602	< 0.05
Disturbance x light	0.051	1	0.051	5.122	< 0.05
Burning x disturbance x light	0.003	1	0.003	0.338	n.s.
RESIDUAL	0.238	24	0.010		
TOTAL (CORRECTED)	10.031	31			

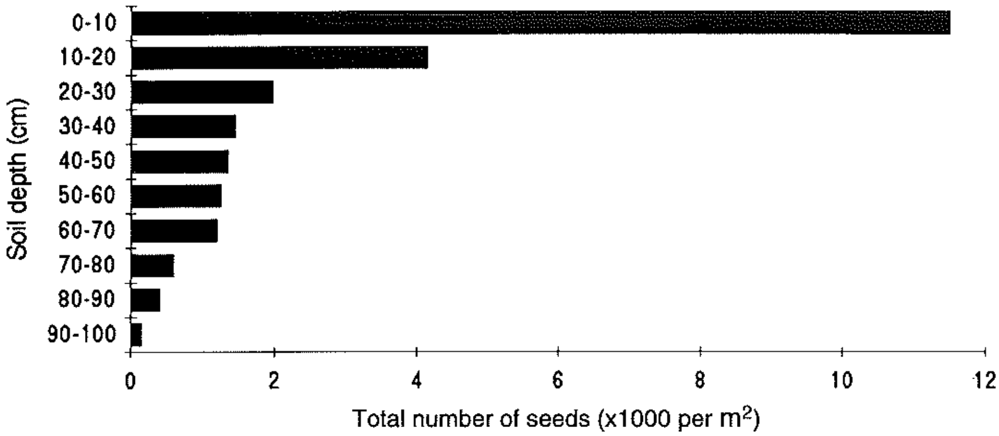


Figure 2. Distribution of blackwood seeds within the soil profile (mean from seven cores).

Nearly 50% of this seed was located within the top 10 cm of the profile. The average seed viability was greater than 94% and there was no indication of a decline in viability even at 100 cm in depth (Table 1).

Effects of soil treatments on germination

The condition of the seedbed produced by the experimental burning treatment was equivalent to the 'medium' to 'high' classifications defined above. This level of soil-heating had a significant effect on the total number of seeds within the upper 7.5 cm section of the soil profile (Table 2, Figure 3a). Burnt soil sections contained less than 40% of the total number of seeds found in unburnt sections. The viability of seeds remaining in the soil sections after burning was significantly lower than in the unburnt treatments. The cumulative effect is that the burnt soil sections contained only 33% of the viable seeds found in unburnt sections.

Burning also had a significant effect on the germination of seeds (Table 2, Figure 3b) and there were significant two-way interactions between burning, disturbance and light. Burning resulted in the germination of more than 95% of the viable seeds. In the unburnt sections, there was some indication of an additive effect of disturbance and light on germination (Tables 2, 3).

The nett effect of burning was that whilst it significantly reduced the number of viable seeds in the upper 7.5 cm section of the soil profile, it also significantly increased the germination of remaining seeds, resulting in significantly more germinants than other treatments (Figure 3c).

Stocking of blackwood following forest regeneration treatments

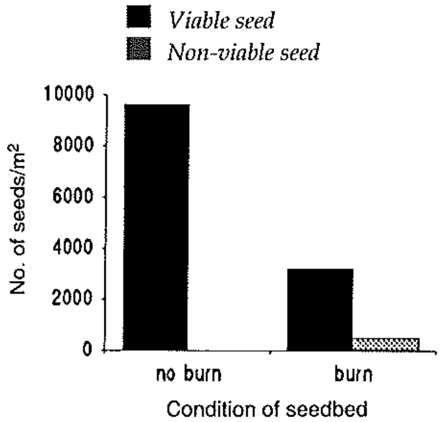
The stocking of blackwood seedlings on various seedbeds followed a consistent trend across the three forest regeneration coupes (Table 4, Figure 4).

Table 3. Percentage germination of viable seeds for various treatments, and significance as determined by analysis of variance.*

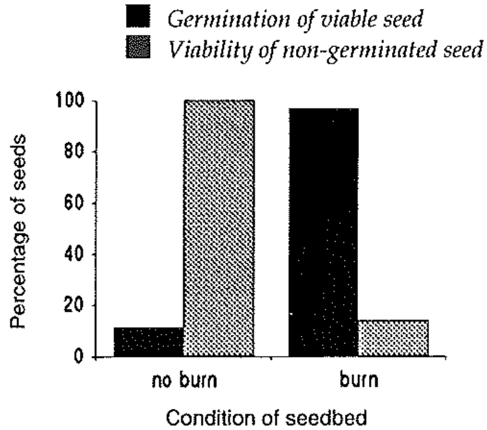
Treatment			Mean % germination of viable seeds			
burn	disturbance	light				
0	0	0	6.1	a		
0	0	+	8.7	a		
0	+	0	9.4	a		
0	+	+	21.2		b	
+	0	0	99.3			c
+	0	+	95.5			c
+	+	0	95.1			c
+	+	+	97.4			c

* Columns of identical letters indicate non-significant subsets at $P = 0.05$.

(a) Total number of seeds.



(b) Germination of viable seeds and viability of non-germinated seeds.



(c) Nett effect of burning on germination and the number of viable seeds in the surface soil.

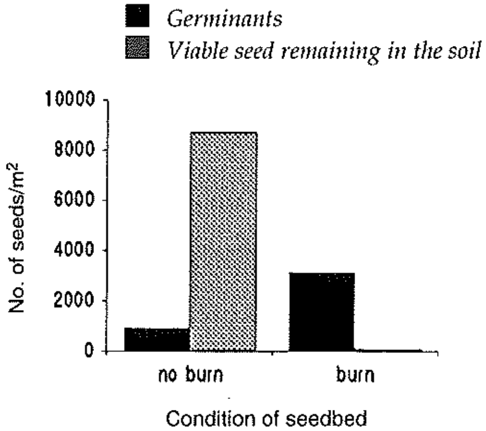


Figure 3. Effects of burning on ground-stored blackwood seed.

The seedbeds created by high intensity burns had approximately half as many seedlings as those seedbeds created by medium to low burns or by logging disturbance alone. However, all seedbed types had stocking levels above the operational standard of 35%. The percentages of ground area covered by the various conditions of seedbed are presented in Table 5 and Figure 5.

Discussion

Ground-stored seed is an important source of regeneration for many plant species (Howard 1974; Cunningham and Cremer 1965). Such seed may remain viable in the soil long after the original plants have disappeared from the site. Howard (1974) recovered viable blackwood seeds in the soil from rainforest that contained no blackwood trees and concluded that the seed had been stored for 'an extremely long period'. Gilbert (1958) noted the regeneration of *Acacia dealbata* after disturbance in rainforest and mixed forest and he postulated that the *Acacia* seed had remained viable in the surface soil for 300–400 years.

The germination of ground-stored seed may occur sporadically in the undisturbed forest and massive germinations are stimulated by fire or by exposure of the soil following logging disturbance or cultivation (Cunningham and Cremer 1965). Regeneration after fire is generally more dense and has a species composition different from that found after soil disturbance (Cunningham and Cremer 1965; Floyd 1966). Following a fire, the majority of germinations typically arise from seed stored in the soil at a depth of 1–6 cm (Shea *et al.* 1979; Portlock *et al.* 1990). As fire intensity increases, lethal temperatures are transmitted to depths of about 10 cm in mineral soils (Humphreys and Craig 1981). For example, Pieterse and Cairns (1987) found that high intensity fire destroyed more than 90% of the viable seed bank of *Acacia longifolia* that was stored within the upper 9 cm of the soil profile.

Germinations below the zone of lethal temperatures are limited by two factors: the

Table 4. Stocking of blackwood seedlings (%) on various seedbed types in three forest coupes.*

Condition of seedbed	Coupe TG21	TG23	CH32	Combined
Hot burn	45	20	38	36 ± 7 (55)
Medium burn	64	64	66	65 ± 3 (194)
Low burn	67	69	72	70 ± 3 (246)
No burn	50	79	63	64 ± 5 (92)
Snig track	50	65	43	51 ± 5 (92)
		(134)	(139)	(406) (679)

* Stocking measured as % of 4 m^2 plots containing a blackwood seedling. Values are the mean for each coupe and the mean ± standard error and number of plots (in brackets) for the combined data.

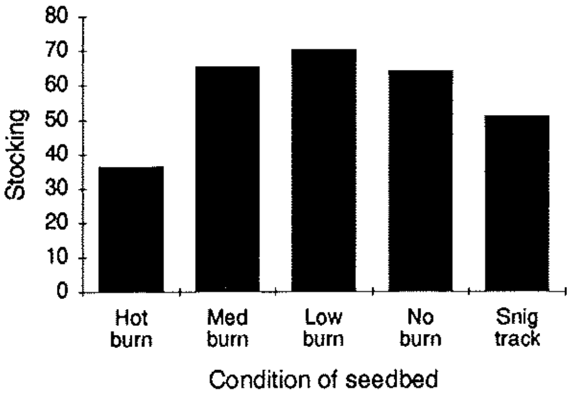


Figure 4. Stocking of blackwood seedlings (% of 4 m^2 plots stocked) on various seedbeds one year after burning (mean of three sites).

Table 5. Percentages of ground area covered by various seedbed types in three forest coupes.

Condition of seedbed	Percentage of ground area* TG21	TG23	CH32	Combined
Hot burn	8	7	8	8 ± 0.4
Medium burn	34	20	30	29 ± 4.0
Low burn	36	44	34	36 ± 3.1
No burn	8	10	17	14 ± 2.8
Snig track	15	19	11	14 ± 2.1

* Assessed as percentage of plots within each type of seedbed.

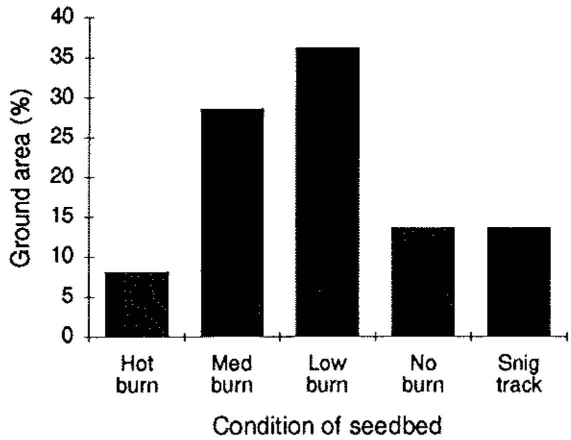


Figure 5. Percentage of ground area covered by various seedbed conditions.

distribution of seed at these depths and the ability of plants to emerge from these depths. Previous studies have generally reported the presence of ground-stored seed to depths of about 12–15 cm (Howard 1974; Floyd 1976; Shea *et al.* 1979). In the current study, viable seeds of blackwood were recovered to a depth of at least 100 cm. The mechanism by which seed occurs at this depth is not clear. Shea *et al.* (1979) report that ants are the primary vector for the vertical and horizontal movement of seed in the soils of the dry sclerophyll jarrah (*E. marginata*) forests. However, the soil dispersal of seeds by ants is less common in wet forest types (Berg 1975) such as the blackwood forests. Other animals such as worms and yabbies burrow to considerable depths in these soils and may indirectly contribute to the vertical movement of seeds within the profile. Seeds may also be washed down cavities created by dead roots, dry soils or up-rooted trees (Garwood 1989).

The emergence of seedlings in the field has been reported to occur from maximum depths of about 9 cm (Cunningham and Cremer 1965; Shea *et al.* 1979). It would therefore appear that seed stored below this level is unlikely to make a contribution to regeneration unless the soil depth is reduced by the burning of organic layers, or there is some redistribution of seed or physical displacement of surface soils.

Fire is generally used in wood production areas as a silvicultural tool to reduce fuel loads and to create a receptive seedbed for the eucalypt regeneration. The results from the soil treatment trials indicate that high intensity burning produces a 'one-off' flush of regeneration by stimulating germination and by depleting the normal reservoir of non-germinated seed stored in the surface soil. A single flush of germination is highly vulnerable since blackwood seedlings are heavily browsed by native animals (Statham 1983). In contrast, the low intensity burning and soil disturbance treatments retain substantial quantities of ground-stored seed for subsequent germinations to replace seedlings lost due to browsing or other factors such as desiccation. This is probably the reason why the relative stocking of blackwood on the high intensity seedbeds was lower in the field studies than in the soil treatment pot trials.

In the unburnt sections of forest coupes, adequate germination of blackwood occurs on seedbeds created by logging disturbance (Figure 4). The results from the soil treatment studies did not determine whether such germination was primarily triggered by physical disturbance or by the increased availability of light. Other laboratory studies have clearly demonstrated that the germination of blackwood is stimulated by physical damage to the seed coat, such as abrasion with sandpaper or clipping the seed coat (Doran and Gunn 1986). It is possible that the disturbance level used in the excavation experiment (removal of litter layer followed by the hand-mixing of remaining soil) did not equate to the levels normally created by logging disturbance.

Overall, the effects of burning on blackwood regeneration are not likely to be uniform, given the variation that may occur in both the pattern of burning intensity and the distribution of ground-stored seed within and between different sites.

The range of burning intensities across the three coupes in this study showed a similar trend, with only 8% of the ground area occupied by high intensity ashbed. The relatively even distribution of high intensity ashbeds forms part of a mosaic of different seedbeds and sources of ground-stored seed. In particular, field observations suggest that the interface between high intensity ashbeds and low intensity or unburnt seedbeds is a favourable zone for germination and subsequent growth.

The spatial distribution of source trees and ground-stored seed for most species is highly variable. Local seed density is determined by factors such as distance from the source trees, mechanisms of seed dispersal, and the rates of predation, germination, persistence and movement in the soil as influenced by the local environmental conditions (Parker *et al.* 1989). At the current study site, there was a very large reservoir of blackwood seed located to a depth of at least 100 cm. The results from the three regeneration surveys also confirmed the presence of seed that was stored deep enough in the soil to survive the soil heating under a high intensity burn. In addition, the very high stocking levels of blackwood regeneration indicated an even distribution of ground-stored seed over a large proportion of the three coupes.

These results are not necessarily applicable to other blackwood sites. For example, on a rainforest site in western Tasmania that had been burnt by wildfire, Hill (1982) found that blackwood did not germinate where the humus layer had been burnt and he suggested that viable seeds were stored in the humus but not in the mineral soil below. Further sampling of ground-stored seed would be necessary to provide information on the possible effects of fire on the regeneration of blackwood in other forest areas.

Conclusions

Prolific regeneration of blackwood from ground-stored seed occurred on all types of seedbed in three forest areas following slash burning and logging disturbance treatments. Soil excavation studies indicated that high intensity burning stimulated a 'one-off' flush of regeneration, with greatly reduced potential for subsequent germinations due to the loss of the reservoir of seeds within the surface horizons. However, on most sites, only a small proportion of the ground area is subjected to a high intensity burn. Most slash burns will result in a mosaic of different seedbed types and each patch of seedbed is likely to contain various quantities of germinants and viable seed, depending upon the intensity of burning and disturbance treatments. On sites that contain a large resource of ground-stored seed within the mineral soil profile, an adequate stocking of blackwood is likely to occur as an initial flush of germinants following burning or disturbance. This appears to be supplemented by continuing germinations from patches containing the surviving resource of ground-stored seed. On such sites, the current practice of slash burning is unlikely to have a detrimental effect on the overall stocking of blackwood provided that the seedlings are given adequate protection from browsing damage.

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