Chapter 8

Seedling Establishment

Only a small proportion of viable eucalypt seeds which fall to the ground ever germinate (Chapter 7) and only a very small proportion of the resulting seedlings ever survive and grow into young trees. Different factors affect the growth and survival of seedlings at different times during their development from a germinating seed to a mature plant. Usually mortality is highest with young seedlings and rapidly decreases with age (Silvertown, 1982). In the first few weeks of life, factors such as depth of planting and soil water availability will greatly influence survival of young seedlings. Seedling survival during this early period will depend on the species involved and the individual vigour of the seedlings as well as chance events. As they grow other factors will influence their growth and survival, such as: light intensity, the genotype of the trees from which the seeds came, temperature, density of seedlings, fungal pathogens, herbivores, weather conditions and climate, as well as competition from other plants, nutrient availability and soil type.

This chapter through a series of experiments, examines the early period of seedling establishment of three common species of the Armidale area: *E. blakelyi*, *E. melliodora*, and *E. viminalis*. These three species were chosen because they were among the worst dieback affected species and it was felt that information concerning them would be valuable for eucalypt management programmes on the Tablelands. Experiments in the laboratory and glasshouses were conducted on these species to examine the relative ability of seedlings to emerge from different depths under various levels of soil moisture. These were accompanied by trials and observations in the field to examine the effects of seed bed and weather on early seedling recruitment and the growth of already established lignotuberous seedlings. The results of these trials were then used to design strategies to encourage natural regeneration and techniques for direct seeding.

8.1 Root and Shoot Length

The first stage in the growth of a seedling is defined by Whalley *et al.* (1966) as the "heterotrophic stage", where its growth depends on the reserves within the seed. This is before the cotyledons emerge above soil level and photosynthesis begins. The length to which shoots and roots grow in this initial stage frequently depends on the size of the seed (Whalley and McKell, 1973). This was found in *E. regnans* by Cremer (1965b), where smaller seeds (averaging 0.6mg each in weight) had a mean hypocotyl length of 25mm, while larger seeds (averaging 1.1mg each) had an average hypocotyl length of 32mm.

The ability of a seedling to emerge from various depths will depend on the length of the shoot that can be produced by the seed before reserves are exhausted. The degree of soil compaction will limit the degree to which a seedling might fulfill its potential length. In this first experiment seeds were germinated in petri dishes in the dark to find the maximum root and shoot lengths that could be produced by the seeds of each species.

8.1.1 Root and Shoot Length Study – Methods

The method used was similar to that of Watt and Whalley (1982a) Ten seeds, chosen at random were placed on damp "Kimpac" absorbant material. These were put into rectangular petri dishes, inclined at 70° to the horizontal and incubated in the dark at a constant temperature of 25°C (Plate 8.1). This temperature was given by Turnbull and Doran (1987b) as the optimum temperature for germination of these species (Table 7.2)

The root and shoot lengths were measured daily until they stopped extending (after about 2 weeks). The seedlings had a few minutes of light each day when they were measured. Three replications of each species were made and the results were subjected to analysis of variance.

One hundred randomly selected seeds of each species were weighed using an electronic Mettler balance to find the average seed weight. The *E. viminalis* trial was a month after the other species. Although conditions were kept as similar as possible some caution should be used in comparing the results.

8.1.2 Results and Discussion

Germination began about the second day after sowing for all 3 species. Growth was most rapid between the third and sixth days and thereafter slowed down. After about the ninth day growth virtually stopped and after about 14–15 days the seedlings began to rot. *E. melliodora* seedlings kept growing for a little longer than the other two species (Fig 8.1).

Both *E. melliodora* and *E. viminalis* seedlings had an average shoot length of about 23mm while *E. blakelyi* shoots were slightly less with an average of 17mm. Very little separated the species in maximum shoot length, all having at least a few seedlings with a shoot length of 27-31mm (Table 8.1).

In contrast to shoot lengths, root lengths varied considerably among the species. *E. viminalis* roots averaged 32mm but in some seedlings grew as long as 55mm. The *E. melliodora* seedlings had roots averaging 23mm with a maximum of 40mm and the *E. blakelyi* roots were much shorter with a mean of 6.9mm and a maximum of 11mm (Table 8.1). The differences between the species is particularly marked in the root:shoot ratios and the root plus shoot values. These emphasize that whereas the species have rather similar seedling heights the differences in the root lengths give the species different growth characteristics (Fig 8.1).

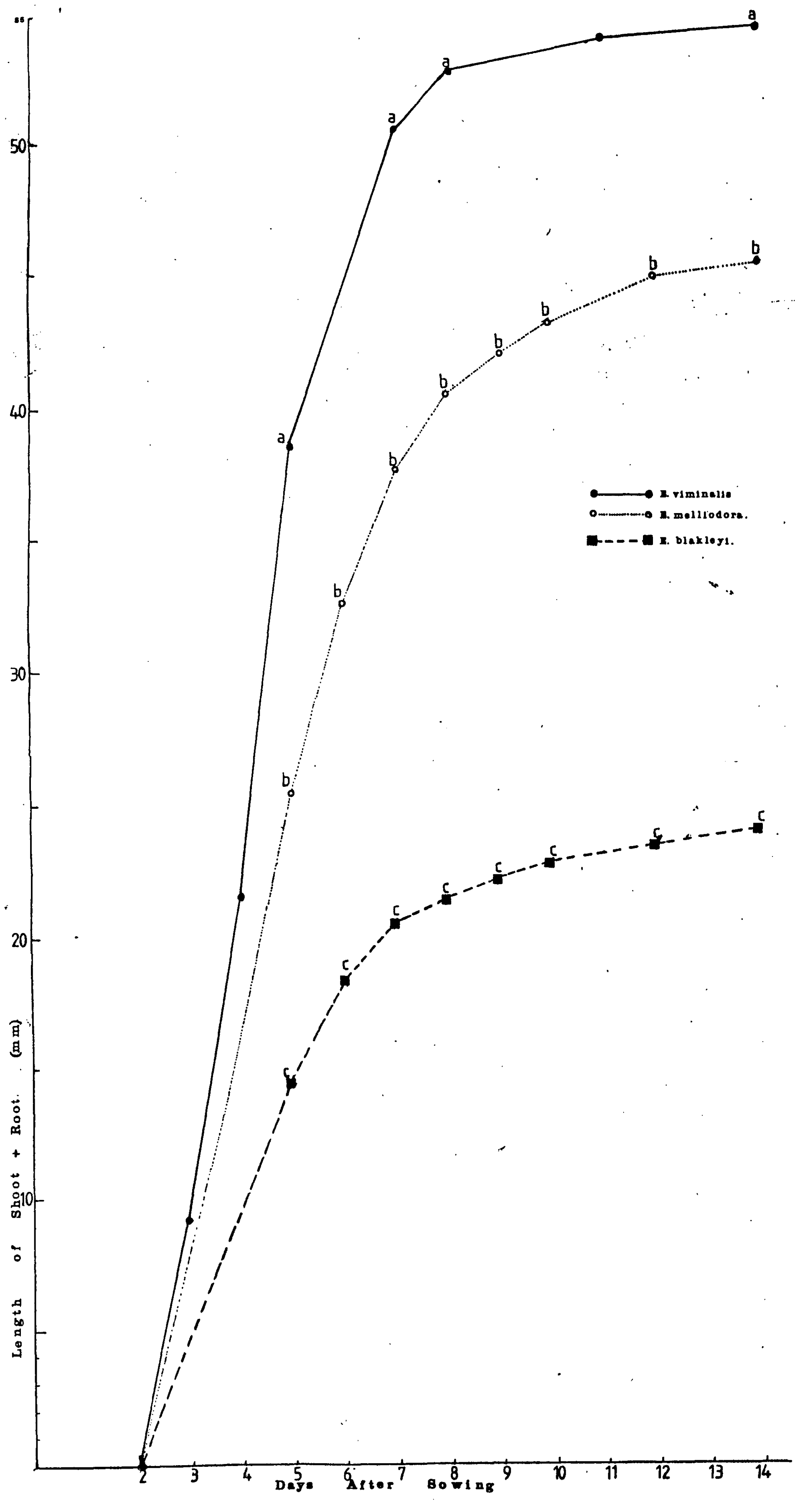


Figure 8.1: Combined shoot plus root lengths of seedlings grown in the dark at 25°C. Small letters (a,b,c) represent significant differences between species at specific times after germination ($P < 0.05$)

Table 8.1: Root and Shoot Lengths of three Eucalypt species when germinated in the dark.

SPECIES	MEAN SEED WT (mg)	FIRST GERMINATED (DAYS AFTER SOWING	MEAN MAXIMUM SHOOT LENGTH (mm) *	ABSOLUTE MAXIMUM SHOOT LENGTH (mm) *	MEAN MAXIMUM ROOT LENGTH (mm) *	ABSOLUTE MAXIMUM ROOT LENGTH (mm) *	MEAN MAXIMUM ROOT PLUS SHOOT LENGTH (mm)*	ABSOLUTE MAXIMUM ROOT PLUS SHOOT LENGTH (mm)*	ROOT TO SHOOT RATIOS +
E. blakelyi	0.26	2	a 17.1	27	a 6.9	11	a 24.0	38	0.40
E. melliodora	0.42	2	b 22.7	28	b 23.1	40	b 45.8	58	1.02
E. viminalis	0.68	2	b 22.9	31	c 31.8	55	c 54.8	80	1.39

* Maximum lengths were taken 14 days after sowing.
\+ Root to Shoot ratios were estimated from Mean Maximum root and shoot lengths.
The letters a, b, c represent significant differences between species at 5% level of confidence.

E. viminalis was the most vigorous of the three species with seedlings growing faster initially and achieving much greater root lengths and slightly longer shoots. *E. melliodora* had similar shoot growth to *E. viminalis* but roots were significantly shorter. *E. blakelyi* seedlings were without doubt the shortest of the three species with very low root:shoot ratios.

The vigour of the three species was directly related to seed weight. The species in order of seedling vigour and seed weight were:-

Most vigorous	*E. viminalis* –	mean seed weight 0.68mg
	E. melliodora –	mean seed weight 0.42mg
Least vigorous	*E. blakelyi* –	mean seed weight 0.26mg.

A similar relationship has been found by Grose and Zimmer (1958a), Ladiges (1974) and Cremer (1965b), with larger seeds germinating faster and having better survival, as well as a longer shoot.

Eucalypt seeds, like the seeds of *Trifolium subterraneum*, have epigeal germination and no endosperm, and the weight of the seed is directly related to the cotyledon area (Black, 1956; Boland and Dunn, 1981). The cotyledons store energy necessary for germination so their size limits the maximum shoot length. Cotyledon size also influences the early growth of seedlings as larger cotyledons can provide more energy via photosynthesis. It would be expected that seedlings from larger seeds would assume dominance over smaller seeded individuals in the early establishment phase.

Although seedling vigour can be directly linked to seed weight up to 9–16 weeks after emergence, it has been harder to find a link between the ultimate growth of seedlings and seed weight (Mackowski, 1979; Boland and Dunn, 1981). It seems likely that within a seed batch the heavier seeds produce faster growing and healthier individuals. This gives them a head start over small seeded individuals, but once established, genetic and site factors become more important in seedling growth. Small seeded varieties may actually be advantaged in some situations, where their slow growth may be an adaptation to drier sites (Ladiges, 1974a;b).

8.2 The Influence of Depth and Moisture on Seedling Emergence

8.2.1 Introduction

This section is concerned with two specific factors which influence seedling establishment – emergence of seedlings from depth and moisture affects.

Cremer (1965b) studied *E. regnans* seed sown at depths of 0, 6, 12, 25, 50 and 100mm. The most favourable depth for seedling emergence was 6mm and no seedlings emerged from depths greater than 25mm. Interestingly seeds on the surface had lower emergence, probably because of more extreme temperatures and drier conditions. Very few seedlings emerged from seeds sown in compacted soil. Most of the seeds germinated 6 weeks after sowing from all depths except surface sown seed which took longer (up to 15 weeks). After 14 months Cremer extracted the remaining seeds. Most had rotted and only a few were still viable.

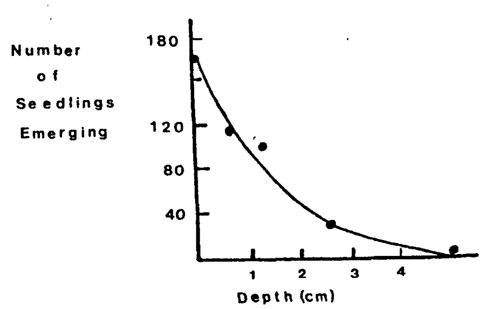


Figure 8.2: Emergence of *E. regnans* seedlings 24 days after being buried at various depths (from Ashton, 1979)

Ashton (1979) produced similar results to Cremer with only a small proportion of *E. regnans* seed germinating from depths greater than 15mm (Fig 8.2).

Free (1951) working with 12 eucalypt species found that seeds sown 5 to 7.5mm deep gave the highest number of emerging seedlings with some seedlings emerging from 12.5mm and in a few of the larger seeded species seedlings emerged from 25mm.

Frequently shallow sown seed (less than 2.5mm) failed to emerge, possibly because of surface desiccation. Seeds heaped together had higher numbers of emerging seedlings than scattered seed.

Drake (1981b) found that no seedlings of *E. signata* emerged from depths greater than 12mm although seeds germinated much deeper. *E. pilularis* and *Angophora costata* emerged from a maximum depth of 25mm.

Table 8.2: Seed Data for Depth-Moisture Trial

SPECIES	COLLECTION	AVERAGE NUMBER OF VIABLE SEED PER SAMPLE OF 50 SEEDS
E. blakelyi	U.N.E. campus April 1983	50
E. melliodora	Puddledock Rd. aprox. 20 km N.E. Armidale April 1983	48
E. viminalis	U.N.E. campus May 1983	47

In the previous section it was found that the three species examined could produce shoots 20, and occasionally 30mm long (Table 8.1). If buried in the soil it could be expected that seedlings would not emerge from seeds buried more than 20mm depth. The following trial compares the ability of these three species to emerge from different depths when exposed to different watering regimes.

8.2.2 Methods

Seeds of the three species were collected and separated from the chaff using a mechanical seed blower. They were tested for viability by placing 5 replications of 50 seeds in petri dishes containing a film of water and left for 5 days at room temperature (Section 7.5.1). Dead seeds, those which did not germinate and blocks of chaff included by mistake because of their similarity to seeds accounted for the lower values (Table 8.2).

Flower pots 22.5 cm in diameter were filled with sand and loam mixed in equal proportion. This was packed down to the lip and watered thoroughly to get the soil compressed and level. At sowing the soil was saturated. Each pot was divided into thirds and 50 seeds of each species were sprinkled on the soil surface. They were covered with the same soil mix to various depths (2, 4, 9, 14, 19 and 23mm), and pressed down. Pots were watered at intervals of 2, 4, 7 and 14 days with an ordinary hose fitted with an oval rose and with the water pressure adjusted to give a gentle even spray which would not disturb the soil surface. The quantity used per watering approximated 12.5mm of rain (500ml). To get this amount accurately the time taken to fill a 500ml container was measured. Water could then be applied quickly with the aid of a stop watch. The experiment was conducted from June to September 1983 in a heated glasshouse. Maximum and minimum temperatures were recorded most days (Fig 8.3).

Seedlings were counted approximately weekly after initial emergence - (15, 22, 28, 33, 45 and 56 days after sowing). Numbers of seedlings emerged were expressed as percentages of viable seed. Three replications were used and the results were subjected to analysis of variance. Because of the possibilities of serial correlation in the sequential observations, analyses were carried out at each time. An overall split plot analysis in time was also performed in order to assess the significance of interactions of depth and species with time. Some caution should be exercised in interpreting the data because of the lack of independence in the observations.

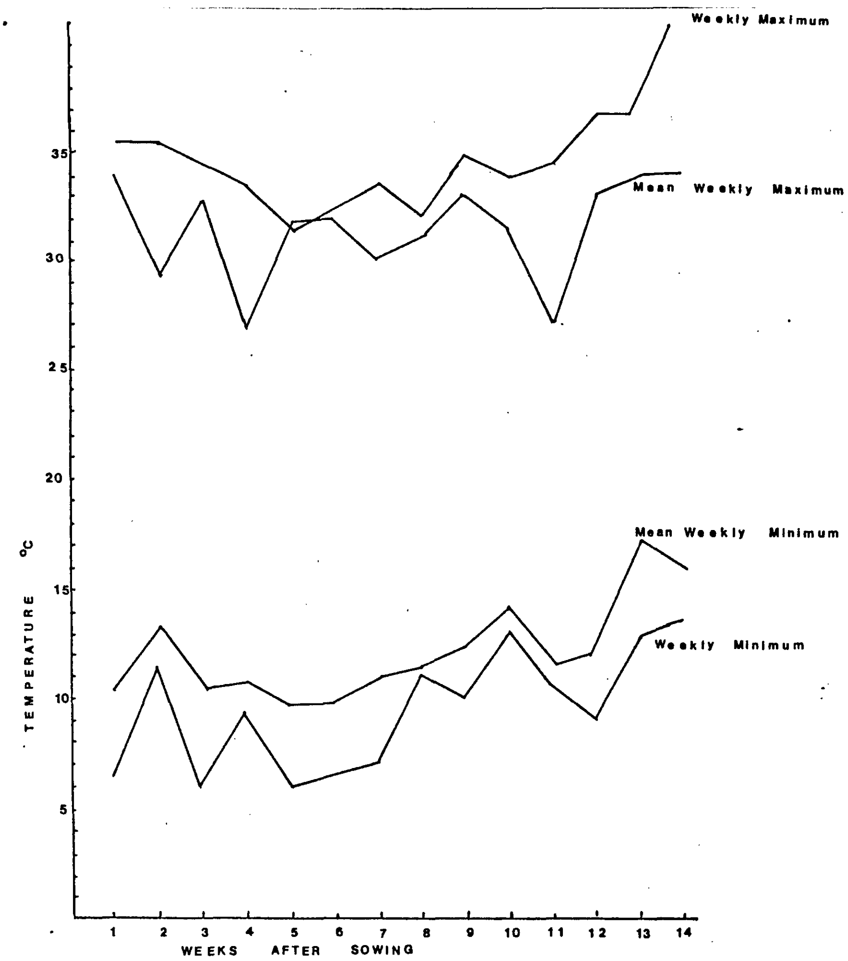


Figure 8.3: Glasshouse Temperatures for the duration of Depth/Moisture Experiment 13 Jun 83 to 20 Sept 83

8.2.3 Results and Discussion

(a) Depth of Sowing and Watering

All species had the best emergence from depths of 2–4mm and pots watered every two days had the highest seedling emergence from those depths where substantial emergence occurred (Fig 8.4). There was a significant depth x watering interaction ($P < 0.05$). There was a tendency for 2mm to give slightly lower emergence than 4mm at all watering treatments but this effect was not statistically significant ($P > 0.05$). Pots watered every four days gave reduced emergence at 9 and 14mm while very little emergence occurred with watering every seven days with seeds sown deeper than 4mm. Very little emergence occurred from below 14mm with any watering regime or at any depth with watering at 14 day intervals.

(b) Species Differences

When considered over all the treatments the three species had significantly different seedling emergence. Percentage emergence of viable seed sown was: *E. blakelyi* – 14%; *E. melliodora* – 17%; *E. viminalis* – 24% when averaged over all treatments. *E. viminalis* seedlings tended to emerge faster than those of the other two species, reaching maximum emergence about 15 days after sowing compared with 28 days for *E. melliodora* and *E. blakelyi* (Fig 8.5). These differences in the species were particularly evident in pots watered every 2–4 days and at depths of 4–9mm (Fig 8.5, Fig 8.6). At other depths and watering treatments there was little to distinguish between the species in numbers of seedlings emerging.

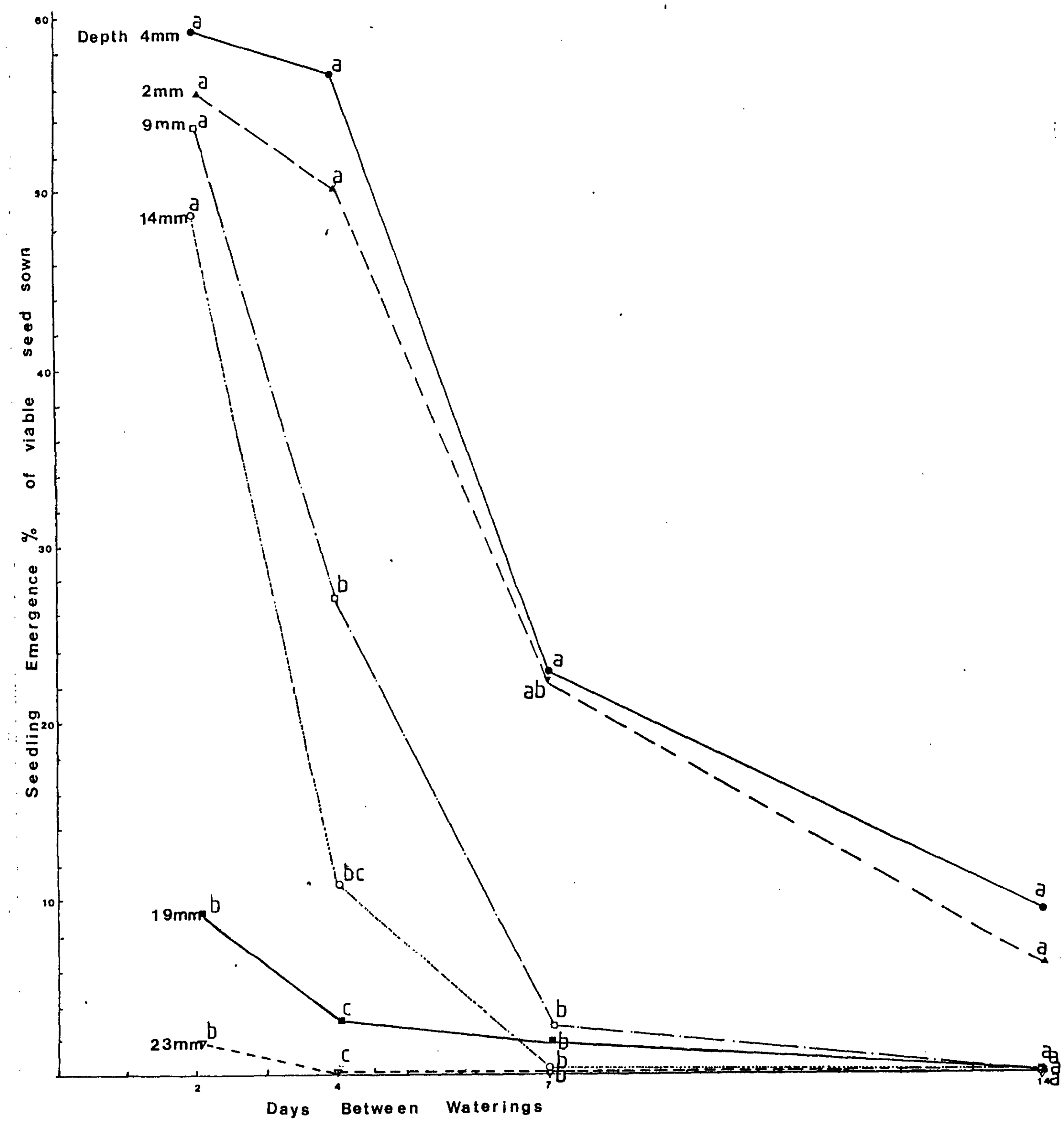


Figure 8.4: The effect of different watering levels on percentage emergence of Eucalypt seed sown at six different depths: Values are meaned over all three species (*E. blakelyi*, *E. melliodora*, *E. viminalis*) and replications. Letters represent signficant differences (P <0.05) between depths at each watering treatment.

There was some difference in the way the species responded to sowing depth (Fig 8.7). At depths of 14mm and deeper there was no significant difference between the species. In fact *E. melliodora* and *E. blakelyi* were indistinguishable at all depths. However at depths of 2–9mm *E. viminalis* had significantly higher numbers of emerging seedlings than the other two species.

(e) Changes Over Time

Emergence of seedlings began about 10 days after sowing and continued for 3–4 weeks, with little further change in seedling numbers except for a slight decrease as seedlings died (particularly in the less frequently watered pots). *E. viminalis* emerged faster than the other species.

When averaged over all species, seedlings tended to emerge over a longer period from depths of 4mm (up to 4 weeks) than other depths (up to 3mm) (Fig 8.5). Seeds watered every 2 and 4 days showed significant increases in seedling emergence up to 3 weeks after sowing while for other watering treatments there was little discernible change over time.

The very low values associated with the deeper depths and the less frequent waterings, made it impossible to detect significant differences between them although some differences seemed apparent when looking at the pots.

Agar (1984) repeated the depth/moisture experiment using *E. crebra, E. dawsonii, E. moluccana* and *E. cladocalyx.* He found a similar relationship between seed weight and the ability of seedlings to emerge from depth. Most of his seedlings emerged from seeds sown from 2–6mm with few beyond 10mm. Watering every two days produced the best results. Emergence was slightly suppressed with daily waterings (due to damping off problems in the glasshouse), and few seedlings emerged from waterings less frequent than every 5 days.

In my trial the fate of seeds which did not germinate remains unknown. It is unlikely that they were eaten by predators in a glasshouse situation. At the finish of the experiment some of the less frequently watered pots were watered daily for a few weeks. A few *E. melliodora* and *E. blakelyi* seedlings emerged in some of these pots from depths of 2–4mm which indicated that a small proportion of the seed remained viable in the soil for a few months at least. The rest probably decayed.

Lower germination and growth rate occurred than was expected. Factors which may have contributed to this were: the soil mixture (which had too high a proportion of loam and should have had vermiculite or composted sawdust added to lighten the mix); the compaction of the soil (which Cremer 1965b found tends to inhibit emergence): the glasshouse (which was unshaded and quite hot). Sowing of the seed on a grid pattern would have made counting the seedlings easier as they were often clumped and difficult to count. Removal of seedlings as they emerged would have made counting easier also.

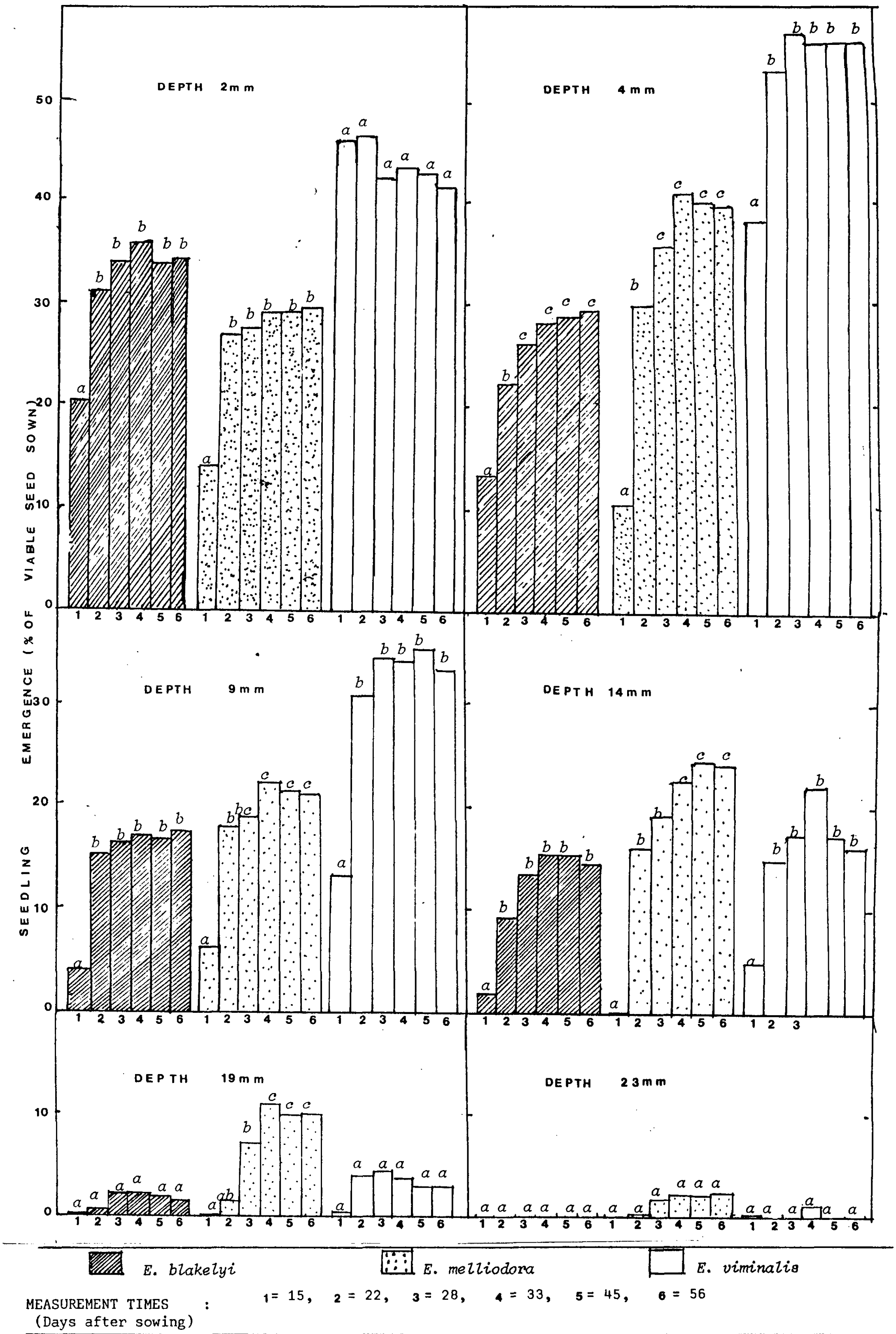


Figure 8.5: Numbers of Seedlings emerging over time for three Eucalypt species (*E. blakelyi E. melliodora E. viminalis*), sown at 6 different depths. Letters in italics repreent significant differences between numbers of emerging seedlings at different times (P < 0.05).

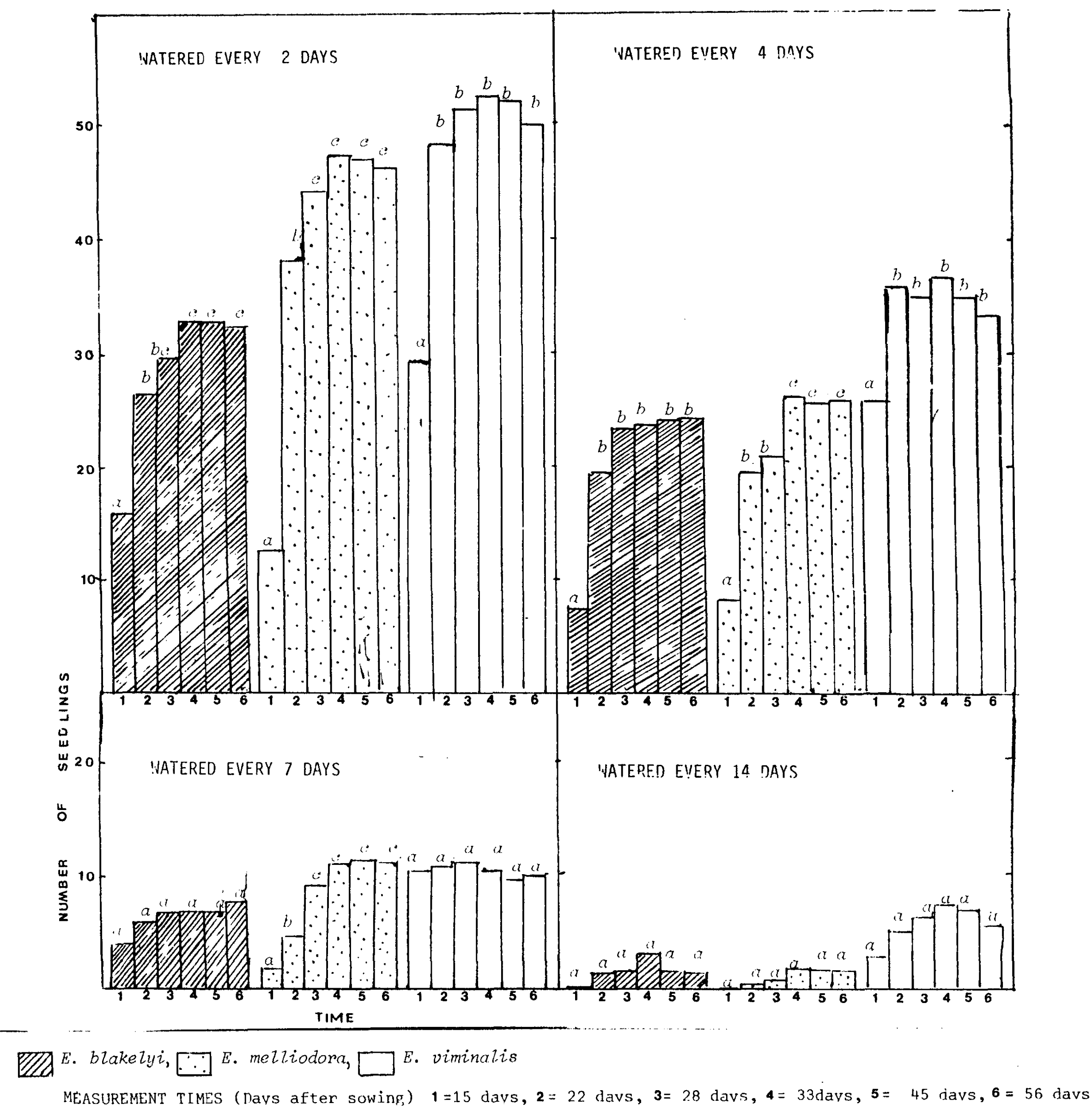


Figure 8.6: Numbers of seedlings emerging over time for three Eucalypt species (*E. blakelyi*, *E. melliodora*, *E. viminalis*), when subjected to 4 different watering regimes. Values are averaged over all depths and replications, and are expressed as a percentage of viable seed sown. Letters in italics represent significant differences between the numbers of seedlings at different times ($P < 0.05$).

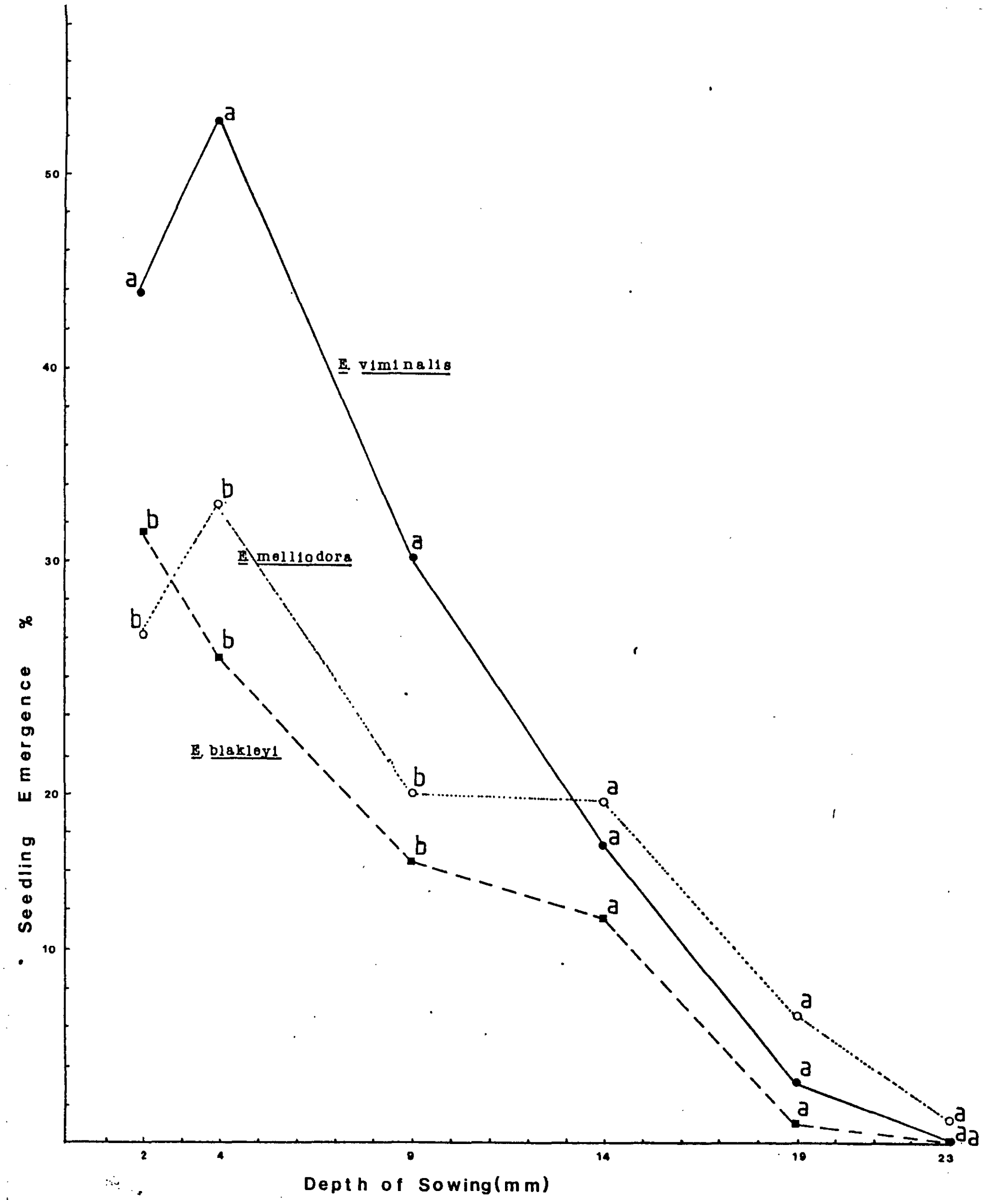


Figure 8.7: The influence of sowing depth on seedling emergence for three eucalypt species (*E. blakelyi*, *E. melliodora*, *E. viminalis*). Values are averaged over all watering treatments and replications. Different letters represent differences (P <0.05) between species at the one depth. Comparisons are not made between the depths.

8.3 Seedling Recruitment Trials

8.3.1 Introduction

Most previous studies dealing with the conditions which affect seedling establishment have concentrated on forest species useful in timber production. Dexter (1967) studied seedling establishment of *E. camaldulensis* in Victoria. He found that seed germination was best in moist spots and in places protected from desiccation, eg. seeds placed under a grass sward or buried 1 cm deep in the soil or ashbed. Subsequent seedling survival and growth however was best in bare cultivated soil or burnt areas, provided sufficient moisture was available. Low survival and growth rates were found in seedlings growing in hard bare earth or amongst light grass. The main cause of seedling death was drought from which Dexter concluded that: "soil moisture, either alone or by interaction with other factors, was the main determinant of seedling survival in their first 9–12 months". Moisture was more limiting under heavy grass or bare soil than under the ash bed and also became more limiting closer to mature trees. Frosts, high temperatures and damage by grazing animals such as insects, rabbits and cattle also accounted for many seedling losses.

Floyd (1960) studied seedling establishment of *E. grandis* near Coffs Harbour. He found a marked difference in sites - the best being on the sloping valley floor where the area was burnt, debris and weeds were absent and the soil crumbly. Sites which were lightly or heavily covered with Wandering Jew (*Commelina cyanea*), or were dry, stony, hard, waterlogged or unburnt and covered with litter gave poorer results.

In regenerating grey ironbark forest 54-74,000 seedlings per hectare became established after August, September and October burns in 1936 and 1937 but subsequent weed growth resulted in the failure of the crop (Henry and Florence, 1966).

Christensen and Schuster (1979) studied seedling establishment of Karri in south west Western Australia on burnt sites. Autumn sowings tended to give slightly higher seedling recruitment than spring sowings, possibly because of more insect predation in spring. Seeds protected with insecticide had higher rates of seedling recruitment. Most seeds germinated after 50–75mm of rain over a 3 day period in April. This included the seeds sown the previous spring, which failed to germinate until the cooler autumn period despite 41mm of rain falling in February. Yellow Podzolic and Red Loam soils had similar seedling recruitment. As well as providing a good seed bed, the ash increase available phosphorus, potassium, calcium, and magnesium, thus enriching the soil with nutrients for regenerating seedlings (Cremer and Mount, 1965). Microbiological and other aspects of the "ashbed effect" were studied by Renbuss *et al.* (1972).

Onans and Parsons (1980) observed natural seedling regeneration of mallee eucalypts in Victoria. It was, they found, a rather rare event and the seedlings were limited to a few favourable sites, always within 8–10m of standing trees, but none under the canopy close to the trunk.

Certain factors emerge from these studies as being important in eucalypt seedling establishment, *viz*: adequate moisture, absence of competition, suitable soil surface/structure, protection

Table 8.3: Seed data for seedling recruitment trials

SPECIES	COLLECTION	NUMBER OF VIABLE SEEDS PER SAMPLE SOWN	WEIGHT OF SAMPLE SOWN (G)
E. blakelyi	Sunnyside Rd. about 20km north of Armidale 15.6.82 (Trial 1) (granite)	285 (1)	0.5
	U.N.E. (basalt) 2.9.82	290 (1)	1.0
E. melliodora	Mixture from 20-25km west of Armidale. Armidale Nov. 1982 (Trial 2) (granite)	74 (1)	1.5
E. viminalis	12-15km south of Walcha 12.2.80 (Trial 1) (Sediments)	160 (2)	0.6
	Mixture of samples (Trial 2)	207 (1)	0.8

(1) Estimated from 10 samples of 0.1gm each germinated in petri dishes for 1-2 weeks at room temperature.
(2) Estimated from samples of 0.125gm each.

from predation, absence of extremes of temperature. The following field trials were designed to test some of these factors in the local situation for the three local species studied in the previous two sections – *E. blakelyi*, *E. melliodora*, and *E. viminalis*.

8.3.2 Methods

The trial was conducted at "The Spyway" about 5km South East of Armidale. The soil is a black cracking clay derived from basalt and the pasture was dominated by *Phalaris aquatica*, *Danthonia* spp, *Bothriochloa macra* and *Trifolium repens* (Appendix VII). The site has a uniform slight slope.

Plots were 2x2m in the first sowing and 1x2m in the second. They were separated by a gap of 30cm. Seeds were weighed so that about 200 viable seeds of each species were sown in each plot, weights being based on Boland *et al.* (1980). Germination tests (as described in chapter 7) were also done to discover the number of viable seeds per sample (Table 8.3).

Three seed beds were tested: **bare soil - burnt** (litter was mounded on to the plot and burnt - the grass sward was too thin to burn by itself due to drought); **bare soil - cultivated** (with rotary hoe, November sowing only); **grass** (untreated). A mulch of woodchips was laid over half the plots, leaving a small gap for the seeds. Surface sown seeds were compared with seeds covered with about 1cm of loam (open plots only - all treed plots were covered with sandy soil - see below). Watering and natural rainfall were compared for both sowing times. Watered plots in the November sowing were watered every 1–2 days for the first month. Plots in which germination occurred were then watered every 2–3 days for about two more months after which only occasionally. About one bucket per plot of water was used. Plots were not watered when it rained which meant the autumn sowing was only watered occasionally.

Plots were replicated at 3 distances from a small group of *E. blakelyi* (Fig 8.8; Plate 8.4) - directly under the trees, on the southern side of them, and about 70m away from them (behind

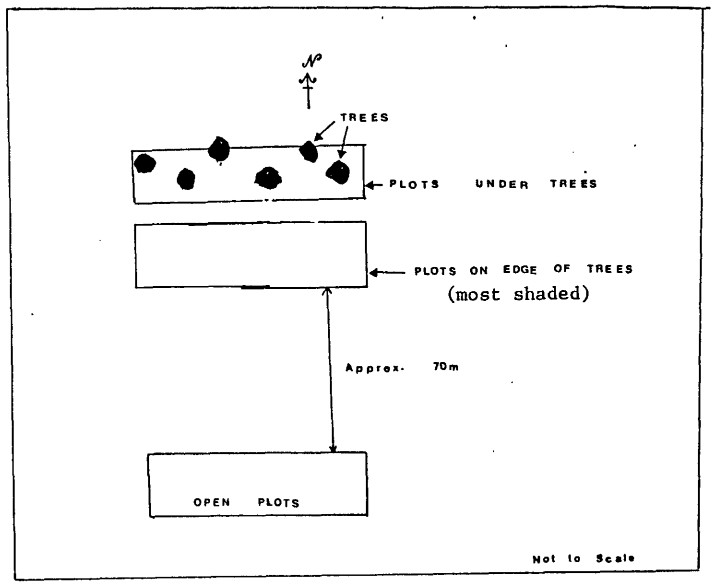


Figure 8.8: Position of plots for seedling recruitment trials

the camera in Plate 8.4). In the November sowing seeds were sown only in the open plots. The open plots were dominated by *Phalaris aquatica* while the treed plots had a mixture of native species (chiefly *Danthonia* species and *Poa sieberana*, native legumes and introduced species such as *Trifolium repens.*

E. blakelyi and *E. viminalis* were sown in November. *E. blakelyi*, *E. melliodora*, and *E. viminalis* were sown in March. There were two replications for each treatment and the plots were arranged randomly within the watering treatments. Maximum and minimum temperatures and rainfall measurements were taken most days at the site (Fig 8.9).

Seed was sown in spring (November) 1982, and autumn (March) 1983. Summer 1982/83 had drought conditions while autumn 1983 was exceptionally wet and mild (Fig 8.9, Fig 8.10, Fig 8.11).

8.3.3 Results

The conditions generally necessary for seedling recruitment combined good weed control and moisture levels and *E. viminalis* was the most successful species. In the November sowing *E. viminalis* germinated faster than *E. blakelyi* but both speces had similar recruitment levels 3 weeks after sowing. However *E. blakelyi* had greater subsequent mortality and by 11 weeks only *E. viminalis* survived (Tab 8.4). In the autumn sowings *E. viminalis* was the most vigorous species, probably by virtue of its greater initial germination and faster growth (Table 8.5).

Recruitment was best on burnt plots throughout. In the open plots for both sowings virtually no seedlings emerged from either grassy or cultivated plots (Fig 8.10, Fig 8.11, Table 8.6). In the autumn sowing in the treed plots, more seedlings emerged amongst the grass than in the open plots but they tended to be spindly and small (Table 8.6).

Covering the seeds increased recruitment markedly. In the November sowing about one third of seedlings emerged from uncovered seed while the remaining two thirds had been covered. The act of watering probably buried the uncovered seeds. In the autumn sowing the difference was

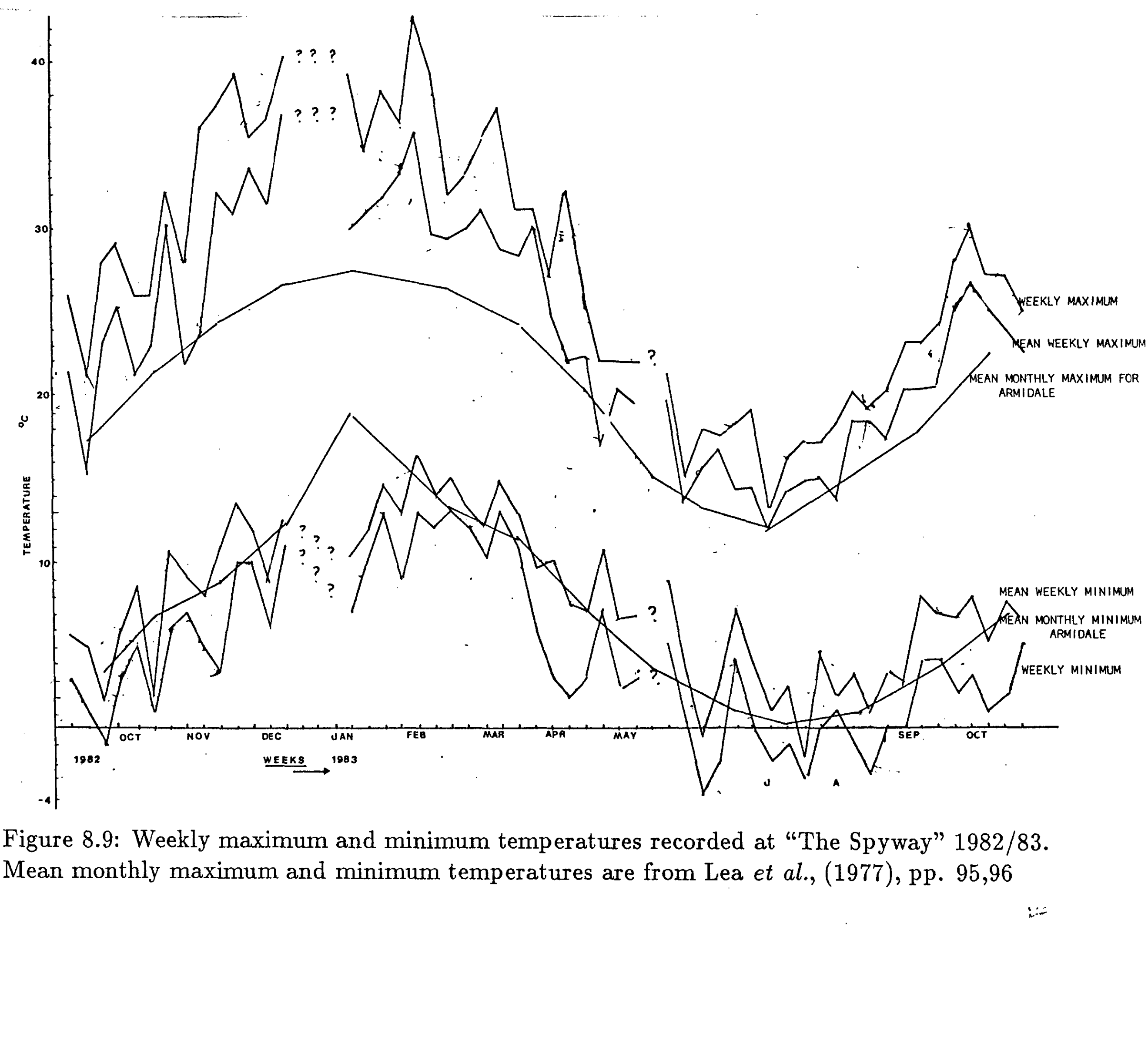


Figure 8.9: Weekly maximum and minimum temperatures recorded at "The Spyway" 1982/83. Mean monthly maximum and minimum temperatures are from Lea *et al.*, (1977), pp. 95,96

Table 8.4: Species comparison for recruitment trials - November 1982 sowing. Values are total number of seedlings emerging over all treatments and replications.

POSITION	SPECIES	WEEKS AFTER SOWING						
		1.8	2	3	4	5	11	40
Open Plots	*E. blakelyi*	0	7	30	18	7	0	1
	E. viminalis	17	23	31	23	21	12	9*
	TOTAL	17	30	61	41	28	12	10

* Seedling Heights ranged from 4-10cm.

Table 8.5: Species comparison for recruitment trials - March 1983 sowing. Values are total number of seedlings emerging over all treatments and replications.

POSITION	SPECIES	WEEKS AFTER SOWING					
		1.5	3	7	21	32	50
Open Plots	*E. blakelyi*	0	4	7	1	1	0
	E. melliodora	8	12	10	4	9	5
	E. viminalis	47	45	42	23	16	16
	TOTAL	55	61	59	28	26	21
Under Trees	*E. blakelyi*	23	44	42	54	?	6
	E. melliodora	6	24	21	17	?	4
	E. viminalis	154	54	24	19	?	9
	TOTAL	183	122	87	90	-	19
Edge of Trees	*E. blakelyi*	57	46	33	20	?	4
	E. melliodora	27	38	33	31	?	1
	E. viminalis	243	298	191	154	?	22
	TOTAL	327	382	257	205	-	27

Table 8.6: Comparison between grassy and burnt plots - Autumn 1983 sowing. Number of seedlings, totalled over both replications.

Position	Treatment	Weeks after sowing				
		1.5	3	7	21	50
Edge of trees	Grass	150	163	116	85	1
	Burnt	170	219	141	120	26
	TOTAL	327	382	157	205	27
Under trees	Grass	66	43	30	42	4
	Burnt	117	79	57	48	15
	TOTAL	183	122	87	90	19
Open plot	Grass	1	4	1	0	0
	Burnt	54	54	59	28	21
	TOTAL	55	58	60	28	21

more extreme - there were about nine times as many seedlings emerging from buried seed as unburied seedlings (Fig 8.10, Fig 8.11).

In the spring sowing, except for one *E. blakelyi* seedling which emerged after the January rains, no germination occurred in unwatered plots, for although October had above average rainfall, November and December were very dry (Fig 8.10). Virtually no seedlings emerged from unwatered open plots in the autumn sowing. In the treed plots, although watered plots had four times more emergence than unwatered plots, plots relying on rainfall had significant recruitment (Table 8.7).

The woodchip mulch led to much higher recruitment levels in the open sites, for both sowing times - virtually all recruitment which occurred was in mulched plots. Mulch also tended to increase recruitment under the trees. However in the shaded area (and to a lesser extent under the trees) the mulch hindered growth because in the gaps made in the mulch to sow the eucalypt seeds a vigorous growth of winter growing clovers and other weeds grew and suppressed the

Table 8.7: Comparison between watered plots and plots with natural rainfall only, at different distances from a group of trees - Autumn sowing. Values are total numbers of seedlings emerging overall treatments and replications.

Position	Treatment	Weeks after sowing 1.5	3	7	21	50
Edge of trees	Watered	247	360	339	182	17
	Rainfall only	80	22	18	23	10
	TOTAL	327	382	257	205	27
Under trees	Watered	161	121	82	75	12
	Rainfall only	22	1	5	15	7
	TOTAL	183	122	87	90	19
Open plot	Watered	48	57	54	26	21
	Rainfall only	7	1	6	2	0
	TOTAL	55	58	60	28	21

Table 8.8: Comparison between mulched and unmulched plots, at different distances from a group of trees - Autumn sowing.

Position	Treatment	Weeks after sowing 1.5	3	7	21	50
Edge of trees	Mulch	124	200	107	67	4
	No Mulch	203	182	150	138	23
	TOTAL	327	382	257	205	27
Under trees	Mulch	106	102	65	52	10
	No Mulch	77	20	22	38	9
	TOTAL	183	122	87	90	19
Open plot	Mulch	50	58	57	28	21
	No Mulch	5	0	3	0	0
	TOTAL	55	58	60	28	21

eucalypt seedlings (Plates 8.5 - 8.7; Table 8.8).

The effect of site was marked on recruitment. The plots on the southern sides of the clump of trees had twice as many recruited seedlings than those directly under the trees and six times as many as the open plots (Table 8.4, Table 8.5). Over the following year these differences were reduced considerably but remained nevertheless.

Most seedlings emerged 2–3 weeks after sowing where moisture was available. In the whole trial, only one seedling was observed emerging some time after sowing. This was a *E. blakelyi* which emerged 3 months after the November sowing after the heavy January rains. Seedling losses were high in the first 3 months (Fig 8.10, to Fig 8.12). In the spring sowing losses were mainly caused by desiccation, although grasshoppers and other insects may have eaten some. In the autumn sowing the main cause of death was weed growth encouraged by the heavy autumn rains - *Phalaris* in the case of the open plots (which grew to over 2m high by November 1983) - and clover and native grasses in the treed plots, which being only one third the height of the phalaris sward was less competitive. Slugs may have contributed to some deaths. Grass was weeded or trimmed amongst the autumn recruits so they could be counted. This probably ensured that more seedlings survived than if weeding was not done.

Once through the first three months mortality slowed, and those seedlings alive after a year were mostly still alive four years later. The seedlings which survived tended to be "fittest" of the group with which they emerged, tending to be taller and faster growing. In plots where only a few seedlings emerged all seedlings eventually died.

In the November sowing the highest value for seedling survival 10 months after sowing was 2% for *E. viminalis* on plots which had been burnt, mulched, watered and where the seed had been covered. Virtually no recruitment came from cultivated or grassy, sites which were unmulched or unwatered, or where seeds were uncovered.

Almost identical results were observed in the same site when the seeds were sown in autumn - where one year after sowing all the seedlings were in mulched, burnt, watered plots with covered seeds. Survival was higher however - with 3.9% of seed sown for *E. viminalis*, 3.4% for *E. melliodora* and 0% for *E. blakelyi*.

Under the trees one year after sowing the best plots were burnt, no mulch, no water (1.7% *E. viminalis*, 0% *E. melliodora* and 0% for *E. blakelyi*), and burnt, mulch, watered (0% *E. viminalis*, 2.7% *E. melliodora*, 0.3% *E. blakelyi*). At the edge of the trees the best plots were burnt, no mulch, watered (1.9% *E. viminalis*, 0.7% *E. melliodora*, 0.7% *E. blakelyi*) and burnt, no mulch, no water (2.4% *E. viminalis*, 0% *E. melliodora*, 0% *E. blakelyi*).

8.3.4 Discussion

The first few months are critical for eucalypt seedling establishment - moisture and competition are possibly the two most limiting factors. The unseasonality at the times of these trials allowed some interesting comparisons. In the spring sowing in one of the driest Novembers on record, the chief limiting factor was moisture. In the autumn sowing, in one of the wettest autumns on record, moisture was far from limiting and competition became more important. Whereas mulch aided eucalypt establishment in the first trial by preserving moisture it tended to hinder it in the second by encouraging "weed" growth in the gaps. These results reflect those of Dexter (1967) who also found that seedling establishment was best where competition from weeds was low and soil moisture non limiting.

Survivorship of seedlings followed the classic survivorship pattern of tree seedlings (Silvertown, 1982) and followed a Deevey Type III survivorship curve. Thus mortality was very high soon after germination but once through the first 3 months mortality levelled out.

As Dexter (1967) reported, moisture in a very important factor limiting establishment. In the November sowing the woodchip mulch helped maintain moisture levels while unmulched plots dried out quickly in the hot dry conditions which prevailed. The season was too dry to encourage much interfering weed growth, although some grass grew among the seedlings in the mulched watered plots. In the autumn sowing because of the very high April/ May rainfall, it

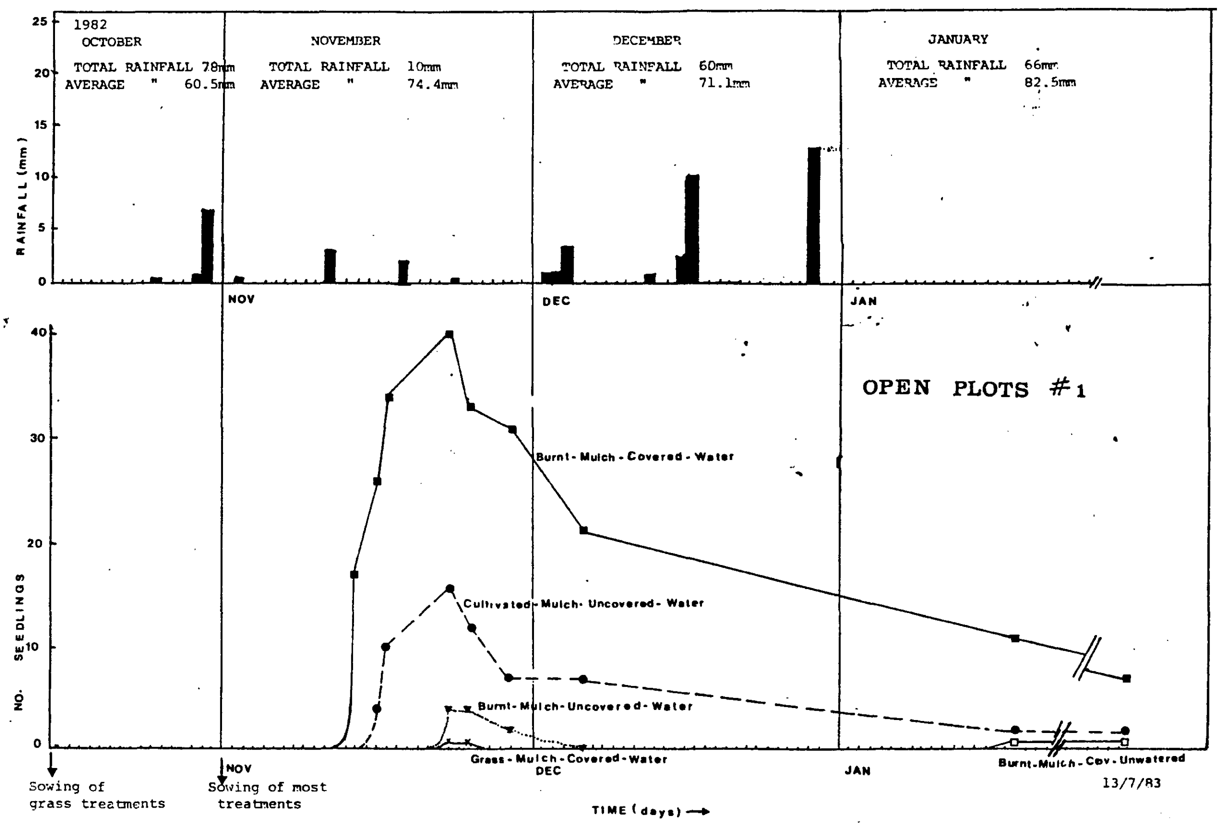


Figure 8.10: Seedling recruitment trial, November 1982 sowing. Open plots. Seedling numbers totalled over both *E. blakelyi* and *E. viminalis* and replications for each treatment. Each line on the figure represents the pooled results of two replications with the combination of the following treatments: Burnt (just before sowing); Grassy (unburnt); Mulched (with woodchips), Covered (lightly with soil); Watered (every 1-2 days for the first month and then every 2-3 days for the next two months); Cultivated (rotary hoe). For full details see methods.

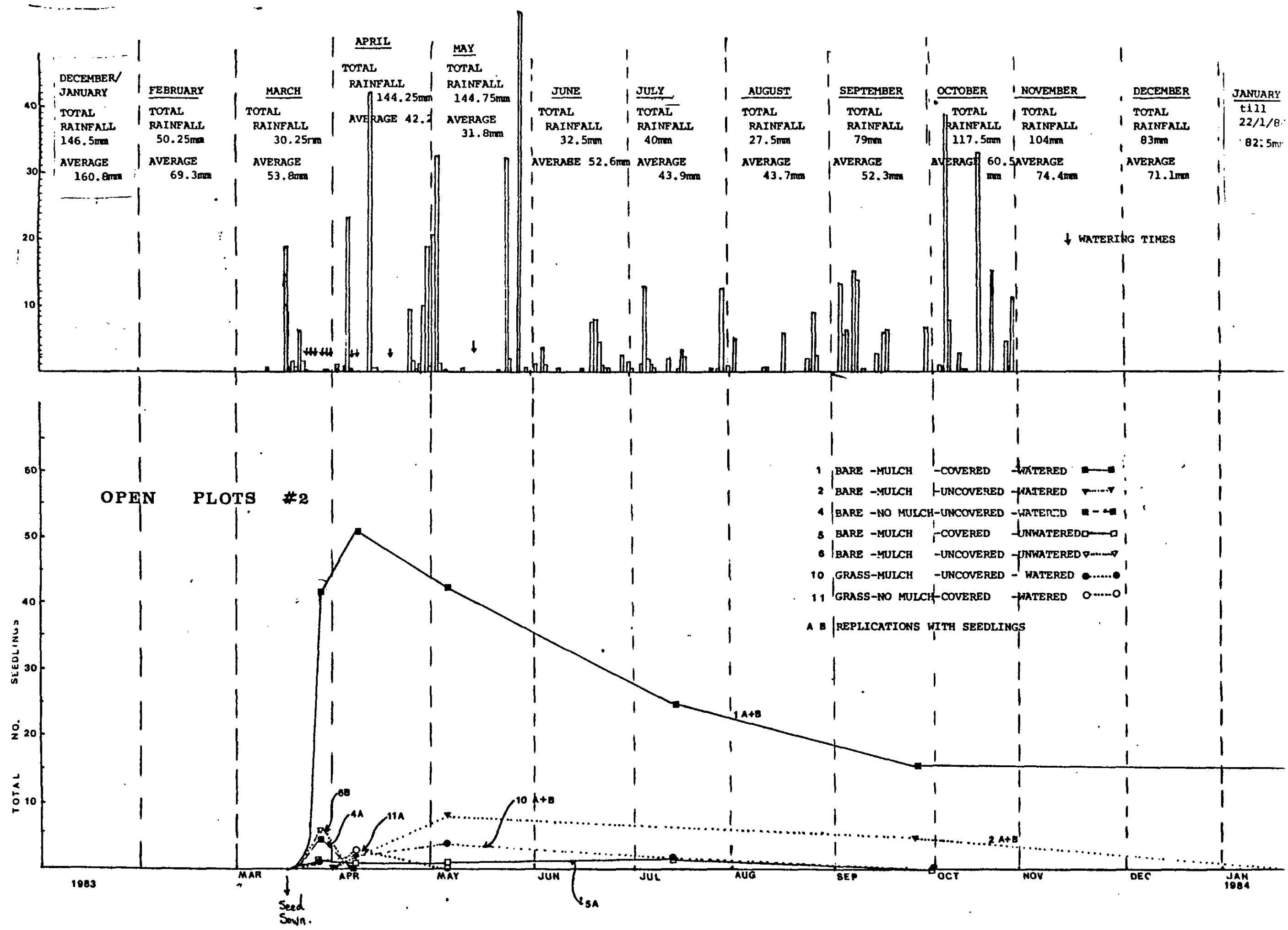
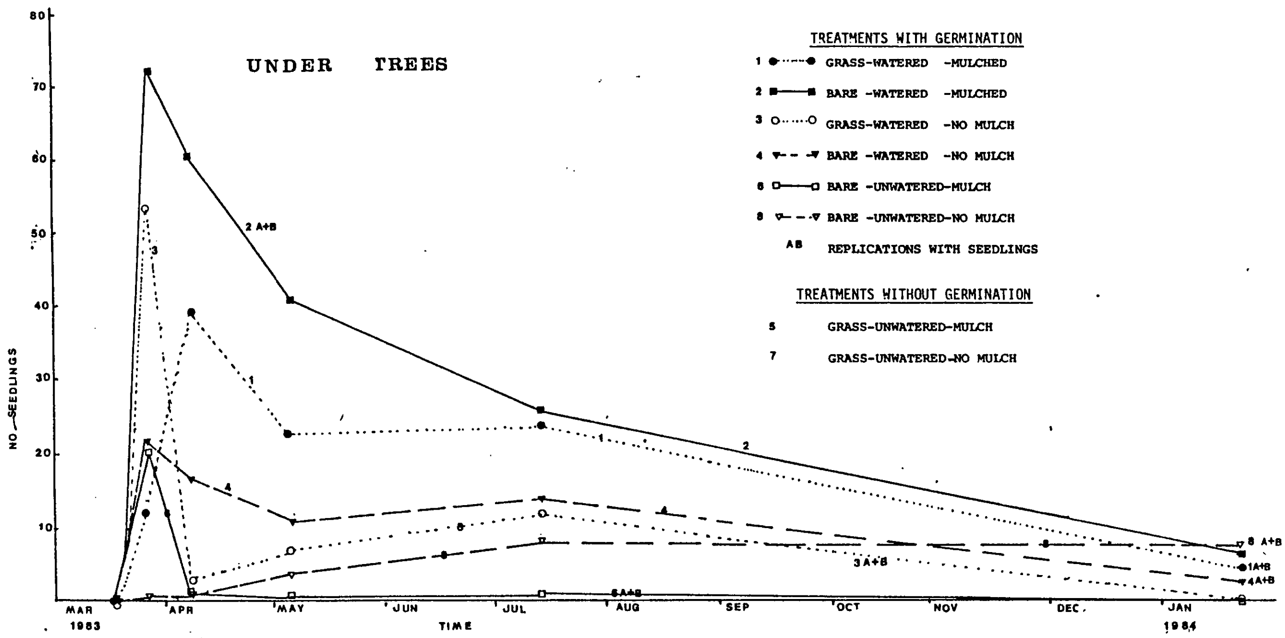


Figure 8.11: Seedling recruitment trial, March 1983 sowing. Open plots. Seedling numbers totalled over *E. blakelyi*, *E. melliodora* and *E. viminalis* and replications for each treatment. Each line on the graph represents a combination of the following treatments: Burnt (just before sowing); Grassy (unburnt); Mulched (with woodchips); Covered (lightly with soil); Watered (only occasionally). See methods for full details of treatments. Two replications (A and B) were made of each combination of treatments.



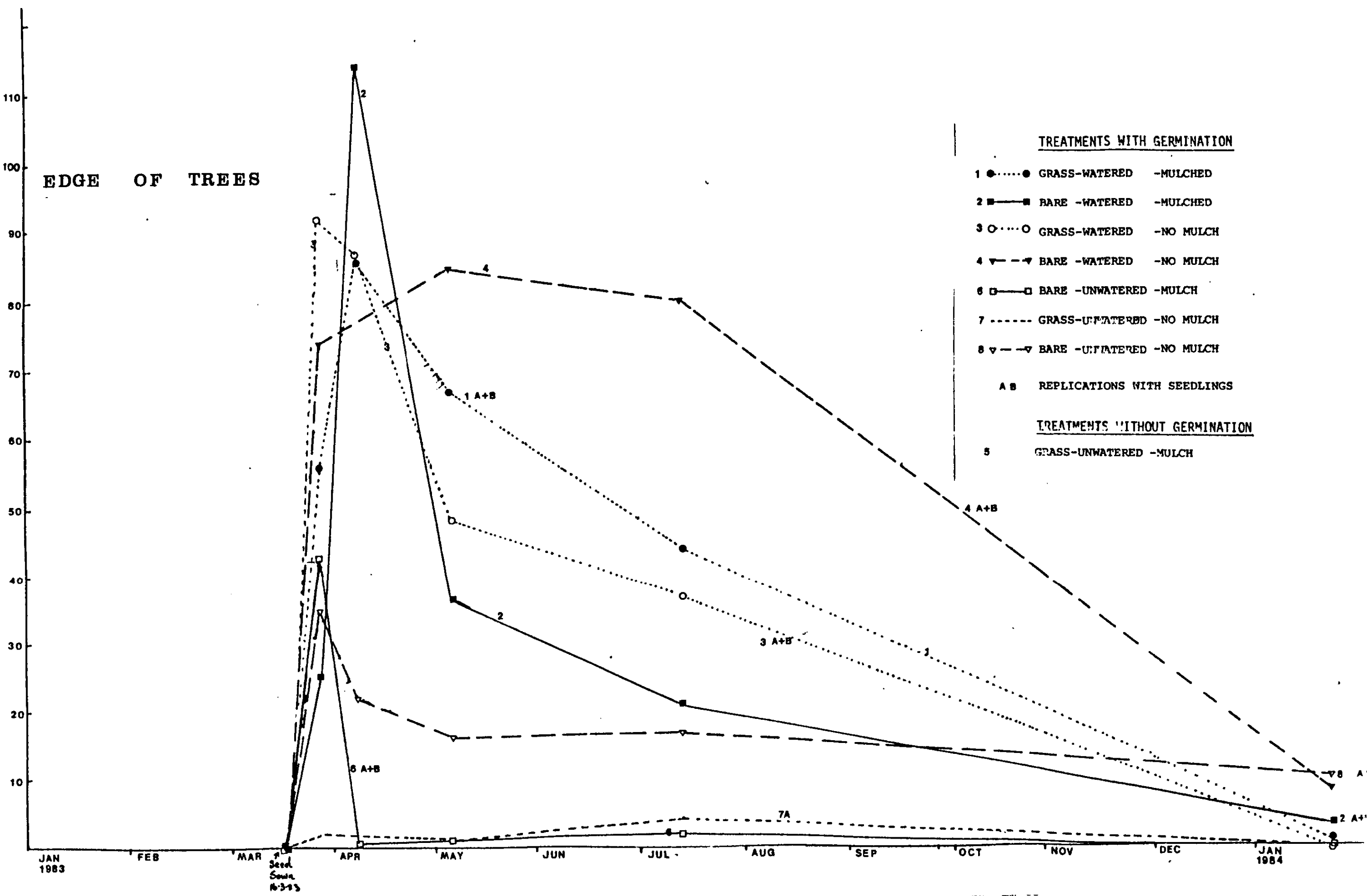


Figure 8.12: Seedling recruitment trial, March 1983 sowing. Treed plots. Seedling numbers totalled over all species and replications for each treatment. See caption of Figure 8.11 and methods for details on the treatments.

was expected that non watered plots would give higher recruitment than occurred, so factors other than simple soil water availability must have been involved.

Covering the seeds, as expected from the experiments in Section 8.2, led to higher seedling emergence, possibly because of protection from desiccation and insect predation. This accords with the results of Free (1951).

The best recruitment occurring in the weed free areas created by burning was expected from the work by Floyd (1960), Dexter (1967) and others. In the natural situation on the Tablelands it is likely that the best eucalypt seedling establishment would be after a fire which coincided with good stores of seed in the canopy and good rainfall subsequently.

Because of the limited dispersal of eucalypt seed (Chapter 6), seedling establishment would probably normally occur near existing trees. This would mean that a clump of trees would gradually extend outwards given suitable conditions - an important aspect of eucalypt regeneration when considering recovery of the populations following a severe episode of dieback. It is significant that the plots on the southern side of the clump of trees had much higher recruitment than the plots directly under the trees or those far away. The shade of the trees (Fig 8.8) aided seedling establishment by preventing the plots drying out between waterings, and by limiting the frosts.

E. viminalis was consistently more vigorous in the early stage growth than *E. melliodora* or *E. blakelyi*. Throughout this trial and those described in Sections 8.1 and 8.2 it had faster seedling emergence and early growth and better survival. The longer root observed in Section 8.1 may partly account for these differences. The differences in the field may be due to the relative capacities to grow on basaltic soil - *E. melliodora* and *E. blakelyi* do not usually grow on such soil (Table 1.3), although near this particular site all three species were growing. The performances of the species may have been affected by the provenances of the seed - little of which was basaltic, and as Ladiges (1974a,b; 1976) reports, this can influence seedling growth. However as the vigour was so uniform throughout these trials (and also the planting trial which followed them on granite - see Chapter 10), there do seem to be intrinsic differences among the species.

8.4 Natural Seedling Recruitment

The trials in this chapter have so far identified some of the conditions necessary for eucalypt seedling establishment. This section reports on observations of natural recruitment in the field and describes more fully, the conditions necessary for seedling establishment from natural seedfall.

8.4.1 Methods

Because recruitment is infrequent, methods to observe it have to be flexible to adapt to changing circumstances. At first, permanent 50 x 1 m transects were laid at three sites and regular observations were made. No seedlings ever became established in these transects so a combination of two other methods were employed. Searches for seedlings were made under the 113 trees monitored for phenology (Chapter 6) when observations were made of the flowering cycle (every 3–4 months). These trees were randomly spread throughout 14 sites, representing a range of vegetation types (Table 6.1). In addition random examinations of all sites were made throughout the study 2–3 times a year, searching for new recruits.

Seedlings were marked with plastic flagging tape and a stake (Plate 8.8) and the following data kept for each one:- species; survival; height; lignotuber size; position relative to parent tree; seedbed conditions; rainfall; reason for death (where possible).

In the hope of encouraging recruitment half of the area under some trees was sprayed once or twice with Roundup herbicide to kill competing plants. Survivorship curves were constructed of the total number of seedlings present at each monitoring time (Lodge, 1981). In the statistical treatment of results all regressions were fitted using the method of least squares (Zar, 1974) and the software package MINITAB.

8.4.2 Results

Survivorship

Seedling recruitment was an extremely rare event at the sites examined. Despite fairly intense searches only about 270 newly recruited seedlings were observed in the six years of this study, under only 16 trees on 6 sites. (Table 8.9).

Most seedlings appeared in the late spring (November–December) of 1985. Only 4 were found germinating in the late spring of 1986, and none at any other time. 80% of the seedlings died in the hot, dry February–April of 1986, within 2–4 months after germination. Survival was best in seedlings which had their first 2–3 pairs of leaves by December 1985 – younger seedlings tended to die once the hot weather set in.

Once through the first four months seedling mortality slowed and after six months seedling survival was *relatively* assured. After three years about 14% of recruited seedlings counted were alive and virtually all of these were under the *E. caliginosa* at Ruby Hills (site 9a) = "Ec 1" see Table 8.9. The log of survivors was plotted against time for Ec 1 and a curve fitted (Fig 8.14). This curve is the classic shape of a Deevey type III survivorship curve (Silvertown, 1982).

Because of the nature of the data, statistical comparisons were not possible between species and sites. However by comparing data from Ec 1 (where recruitment was successful) with that of other trees and sites where it was not successful, some interesting results emerge. Rainfall, seedfall, seedbed, and seedling numbers for Ec 1 are shown in Fig 8.15.

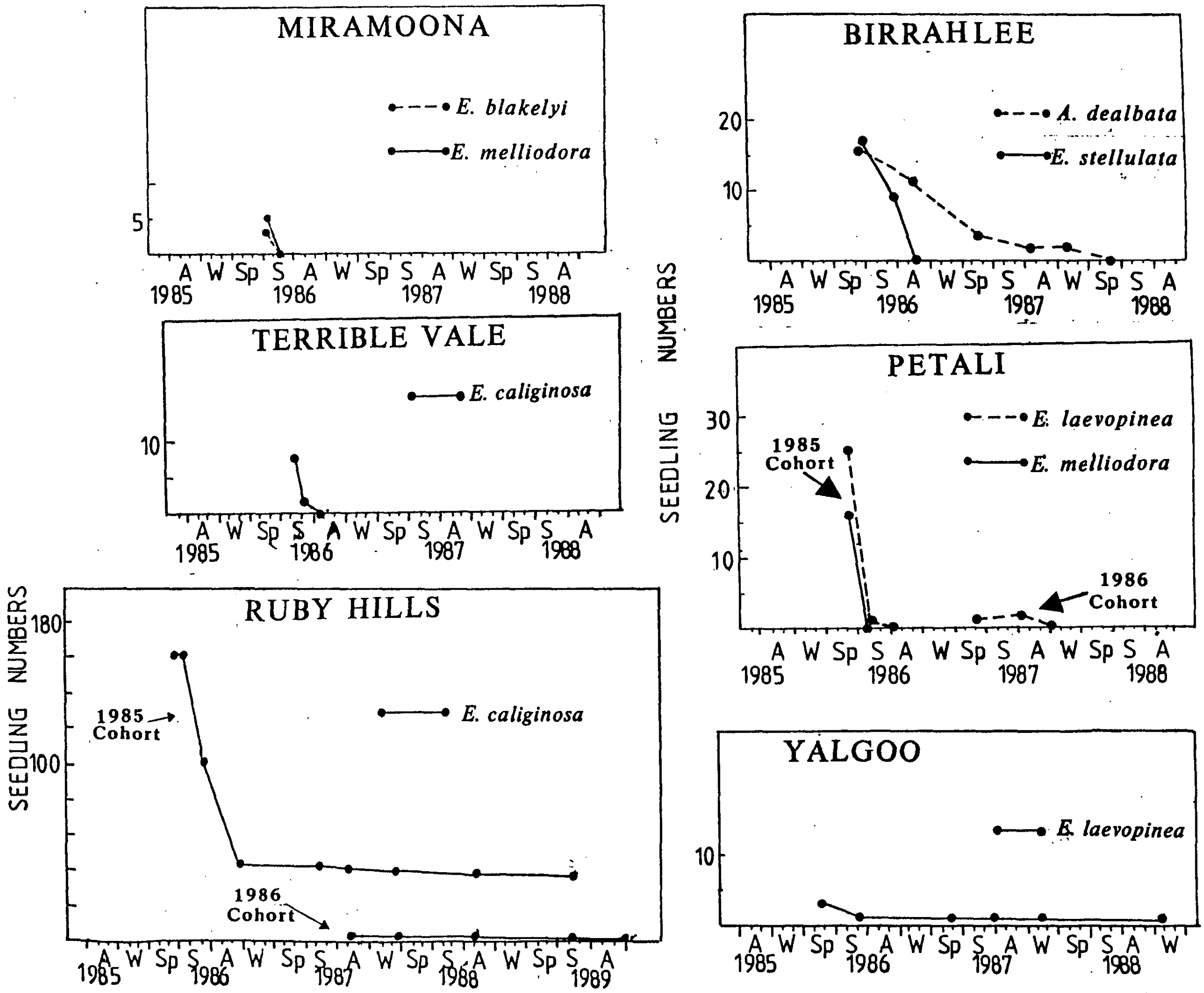


Figure 8.13: Survivorship graphs for recruited eucalypt and acacia seedlings at each site recruitment was observed

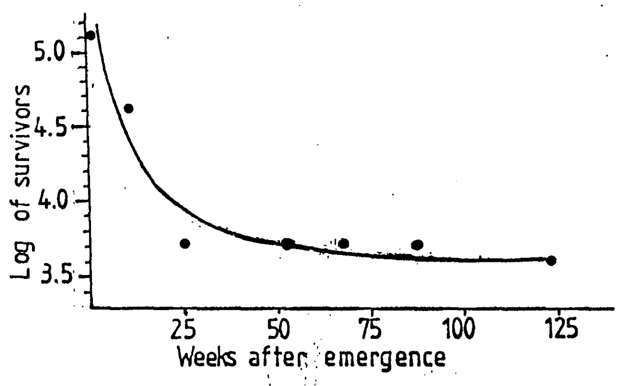


Figure 8.14: Log of survivors against time for recruited seedlings under *E. caliginosa* at Ruby Hills (Site 9a) – "Ec 1"

Table 8.9: Seedling recruitment: Summary

Species/Site	Number of new recruits	Number of trees under which recruitment observed	First observed	Survival after 3 months Number	%	Survival after 4 months Number	%	Survival after 6 months Number	%	Survival after 1 year Number	%	Survival after 3 years Number	%
E. blakelyi													
Petali Dam (8a)	1	1	Early Nov. '85	0	0	0	0	0	0	0	0	0	0
Miramoona (6a)	3	1	Early Dec. '85	0	0	0	0	0	0	0	0	0	0
E. caliginosa													
Ruby Hills (9a)	(161)	1	Early Nov. '85	(118)	(63)	NA		(42)	(26)	42	26	36	19
	2		Dec. '86	2	100	2	100	2	100	2	100	1	50
Terrible Vale (12b)	8	2	Early Dec. '85	2	12	0	0	0	0	0	0	0	0
E. laevopinea													
Petali Dam (8a)	26	3	Early Nov. '85	1	4	0	0	0	0	0	0	0	0
	2		Late Oct. '86	0	0	0	0	0	0	0	0	0	0
Yalgoo (16a)	3	2	Late Oct. '85	1	25	1	25	1	25	1	25	1	25
E. melliodora													
Petali Dam (8a)	16	2	Early Nov. '85	1	6	0	0	0	0	0	0	0	0
Miramoona (6a)	5	2	Early Dec. '85	0	0	0	0	0	0	0	0	0	0
E. stellulata													
Birrhalee (2b)	17	2	Late Nov. '85	9	53	0	0	0	0	0	0	0	0
TOTAL													
6 Sites	272	16		133	49	NA	NA	53	19	52	19	38	14

Figures in () have been extrapolated backwards from 42 seedlings counted at 12 months of age using the survival curve for a sub-sample of 46 original seeldings. NA – data not available.

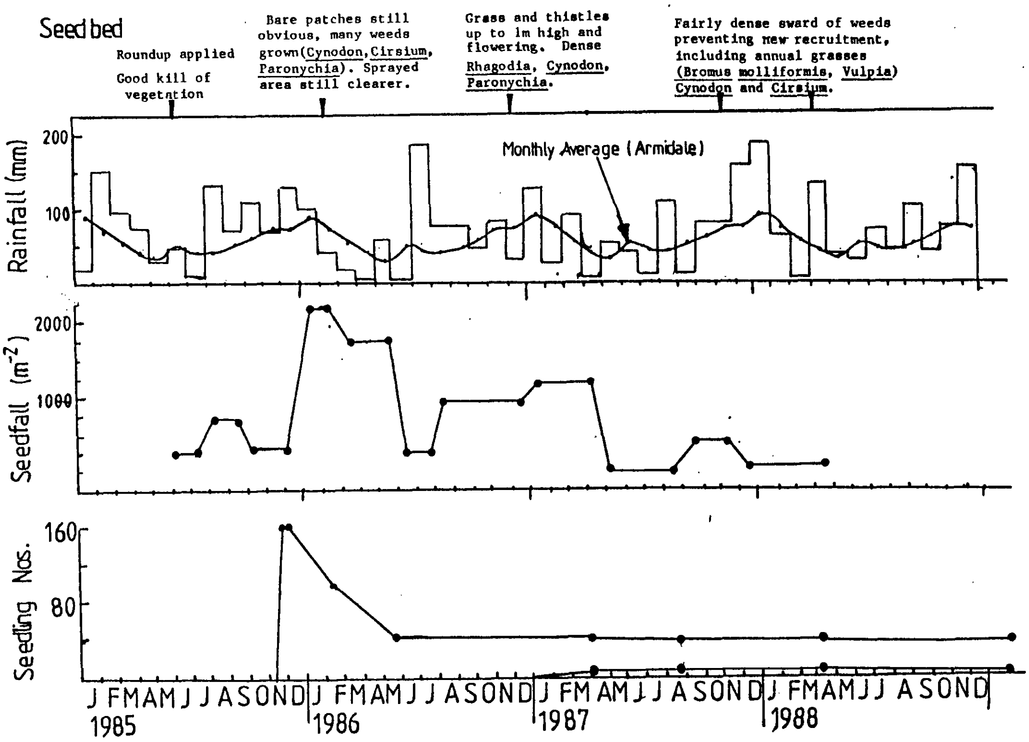


Figure 8.15: Seedling recruitment, rainfall, seedfall, and seedbed conditions for *E. caliginosa* at Ruby Hills (Site 9a) – "Ec 1"

Rainfall and Recruitment

The rainfall associated with the good seedling recruitment of spring 1985 was well above average (Table 8.10). As a prelude to spring of that year the August rainfall was very high at all sites (close to three times the average). In the spring, when seedlings would have been germinating, soil moisture was maintained with about average rainfall in September, well above average rainfall in October and slightly below average rainfall in November. What was very significant was the high rainfall in December which was maintained into January at some sites.

The differences in rainfall between the sites partly explains the differential seedling establishment observed. Ruby Hills, the southern-most site, had a total rainfall of 605 mm in the 26 week to period August 1985 to January 1986. This is 1.5 times higher than the Armidale average for the same period (392 mm) and 100–130 mm more than at other sites. Miramoona/Petali/Yalgoo had 504 mm (1.3 times the Armidale average) and the Kentucky sites (Birrahlee and Terrible Vale) had 472 mm (1.2 times the average) in the same period.

In the February to March 1986 period, rainfall plummetted to only about 35% of the Armidale average, and all sites were equally affected (Table 8.10). However the rainfall at Ruby Hills had maintained its advantage in the critical November–January period at 1.2 times the average, while the other sites had only average or below average rainfall at that time. So although sites were equally affected by the dry spell, the extra 100 mm more of rain that Ruby Hills had between August and January (an average of 5 mm per wek), and particularly the better December/January rainfall, must have been enough to allow seedling survival through the dry period. Seedlings at Birrahlee for example (Plate 8.9) w ere well established in February 1986, and only died when conditions became extreme. Had soil moisture been as well charged as at Ruby Hills it is likely that many seedlings would have survived.

The pattern of high spring and early summer rainfall was not repeated in 1986/87 (Table 8.10) which, in conjunction with poorer seedbed conditions on most sites, accounted for the low seedling recruitment observed in that season. However in the spring/summer of 1987/88 there was better rainfall than even the successful 1985/86 season. Ruby Hills had 1.65 times the Armidale average and the other sites had 1-3–1.4 times the average. Recruitment might have been expected, but by then the seedbed of all sites was unsuitable for recruitment, having a dense sward of grass. Also the seed crops in many trees had declined, thus no recruitment was found in that season.

Seedbed and Recruitment

Recruitment only occurred where the grass sward was thin or the soil bare, and survival was best where weed growth was at a minimum (Table 8.11). About one half of the seedlings became established in naturally clear areas, usually under stringybark trees which (particularly on poorer soil) often had a considerable bare area with a mulch of twigs and fruits. Slightly less than a half of the seedlings became established in areas which had been sprayed with Roundup herbicide in the September before and a few seedlings became established in the bare patches amongst the grass sward. No seedlings were found actually emerging amongst grass.

Table 8.10: Rainfall comparison of sites where seedling recruitment occurred. Values are in mm.

		Ruby Hills	Miramoona Petali Yalgoo *	Birrhalee Terrible Vale +	Armidale Mean
1985	August	131.8	115.5	103	43.7
	Sept.	71	49	61	52.3
	Oct.	108	101	92.3	60.5
Total	Aug-Oct	310.8	265.5	256.3	156.5
	Nov.	68.8	52	42.5	74.4
	Dec.	128.3	117.5	109.5	71.1
1986	Jan.	97	69	63.8	89.7
Total	Nov-Jan	294.1	238.5	215.8	235.2
Total Aug. '85 - Jan. '86		604.9	504.0	472.1	391.7
1986	Feb.	41.3	52.5	36	69.3
	Mar.	17.8	11	2.8	53.8
	April	1.5	5.5	5.3	42.4
Total	Feb-Apr	60.6	69.0	44.1	165.5
	May	58.5	65.5	70.5	31.8
	June	4.8	5	3.5	52.6
	July	184	167.5	180.8	43.9
Total	May-Jul 1986	247.3	238.0	254.8	128.3
Aug '86-Jan '87		434.3	427.5	444.6	391.7
1987	Feb-Apr	119.9	152.5	160.6	165.5
	May-Jul	103.1	111.6	127.6	128.3
Aug '87-Jan '88		647.6	535.5	517.4	391.7
1988	Feb-Apr	199	?	?	165.5

* Based on rainfall at Miramoona - all within 5km of each other.
\+ Based on rainfall at Birrhalee - within 5km of each other.

Over the two months following germination (December–January) weed germination was vigorous at most sites with the good rains, and at the sites dominated by annual exotics weed growth became quite competitive eg: Miramoona – *Hordeum leporinum, Lolium* sp.; Birrahlee – *Cirsium vulgare, Chenopodium carinatum, Trifolium repens, Solanum nigrum, Tagetes minuta, Hydrocotyle bonariensis, Festuca arundinacea*; and Terrible Vale – *Amaranthus viridis, Chenopodium carinatum, Trifolium repens, Silybum marianum.*

Despite the weed growth bare patches remained evident on the sprayed areas (eg. Plate 8.10). On the sites dominated by native species and where the soil was naturally bare, weed growth did not become competitive. Once the dry weather set in weed growth was inhibited and further weed germination was prevented. Indeed annual weeds were possibly more affected by the dry weather than the eucalypt seedlings and during this period water stress became a much more important factor in eucalypt mortality than weed competition.

Weed growth in the second season had very little affect on seedling survival although it may have had an effect on seedling growth (see below). Grass and weed growth in the second and third seasons had returned to produce a relatively normal sward up to 1 m high at all the sites (Plate 8.11). Any seedlings still alive (under Ec 1) co–existed and eventually broke through the sward (Plates 8.12 and 8.13).

The lack of replication makes it difficult to unravel the affect of herbicide spray from other factors. It was employed under 6 trees on the sites where exotic pasture and weed species

Table 8.11: Seedbed condition and seedling recruitment for all sites recruitment was found. + is a sample of seedlings marked. * Total population of seedlings estimated from original sample. NA - Not applicable.

Site	State of seedbed at time of recruitment	Number of Eucalypt seedlings recruited: Not Herbicided – Ground fairly bare around tree	Not Herbicided – Bare patches in grass sward	Not Herbicided – Grass Sward	Herbicided – No living herbage	Eucalypt seedling Survival at 2 months (%) / State of seed bed	Eucalypt seedling Survival at 5 months (%)	Eucalypt seedling Survival at 2 years – Not Herbicided (%)	Eucalypt seedling Survival at 2 years – Herbicided (%)
Miramoona	17.12.85 Dense sward of annual fruiting - *Lolium perenne, Hordeum leporinum, Cirsium vulgare,* + other annual weeds.	NA	8	0	NA	0 (29.1.86) Most herbs dead or fruiting, some new germination.	0 (15.4.86) Most grasses & herbs dead, lying flat.	0	NA
Birrhalee	27.11.85 Improved pasture. Dominated by *Festuca arundinacea, Vulpia* sp. *Hordeum leporinam, Trifolium repens, Cyndon dactylon* and *Bromus molliformis.* Grazed flat and sprayed in September.	NA	0	0	16	56% (20.2.86) Weed germination good but still clear areas around seedlings of 3-10cm diameter. Annual weeds mostly: *Cirsium vulgare, Chenopodium carinatum, Solanum nigrum, Trifolium repens, Tagetes minuta, Vulpia* sp., *Hydrocotyle bonariensis, Festuca arundinacea.*	0 (22.4.86) Most grasses & herbs dead, dried off or fruiting.	0	0
Petali	6.11.85 Natural pasture, much bare soil. Germination of clover, *Chenopodium, Paronychia, Urtica, Hordeum, Bromus molliformis.*	42	0	NA	NA	0	0	0	NA
Ruby Hills	4.12.85 Natural pasture. Most of area fairly bare. Half of area under tree sprayed June '85 and Sept. '85.	14+	0	0	+32	63% (12.2.86) Bare areas still obvious, many weeds grown: *Cynodon dactylon, Cirsium vulgare, Paronychia brasiliana.* Sprayed area clearer.	26%*	5%	19%*
Terrible Vale	20.12.85 Sprayed in early spring, once. Much of area clear but vigorous germination of annual weeds: *Amaranthus viridus, Chenopodium carinatum, Trifolium repens, Silybum marianum, Geranium* sp.. Rest of site dominated by *Lolium perenne* and *Hordeum leporinum* and *Silybum.*	3	0	0	5	25% (6.2.86) all in sprayed area. Weeds not grown, heavily wilted. Bare patches still predominant. Eucalypt seedlings wilting.	0 Most annuals dead or fruiting.	0	0
Yalgoo	23.10.85 Much bare soil, native grasses.	3	0	0	NA	30% Herbs dried off or fruiting.		0	NA
Total		123	8	0	53				

dominated (Birrahlee, Ruby Hills, Terrible Vale) and at those sites virtually the only seedlings which became established were in the area which had been cleared with spray. The chemical did not prevent a second spring germination of weeds but did seem to inhibit weed growth for enough time for eucalypt seedlings to become established.

One of the trees sprayed subsequently died quite rapidly about 6 months after spraying (at Terrible Vale) and the health of a second (Ec 1 at Ruby Hills) steadily declined over 1987/88; 2–3 years after spraying (Plate 8.13). Whether these events were related to the chemical is unknown but it indicates that extreme care should be taken to prevent any herbicide drift touching the tree or moving through the soil to the roots.

Seedfall and recruitment

Table 8.12 presents data of seedfall and seedling recruitment for all trees which had adequate seedfall data plus trees where recruitment occurred. Constraints of the project meant that seedtraps were too small and not monitored frequently enough and there was not enough replications or trees per species to provide against misadventure, eg. cattle damage, beetle damage, and death of trees (all of which happened). Although the seedfall data should be approached with some caution the results are interesting.

At many of the trees recruitment occurred before the seedfall peak was reached (see Fig 6.9, Fig 8.15). This was observed in *E. caliginosa*, *E. laevopinea*, and *E. stellulata*. Although no recruitment was observed under trees of *E. pauciflora*, *E. nova–anglica*, *E. viminalis*, or *E. radiata*, the seedfall peak came after the time of main seedling establishment also, ie. in all these species recruitment occurred in late October–early December while the seedfall peak came later in the summer or in summer–autumn. For *E. melliodora* and *E. blakelyi*, where seedfall peaked earlier than the other species, recruitment coincided with the seedfall peak.

In all cases where recruitment occurred, the fruit crop was heavy (or sometimes medium – Table 8.12). The level of seedfall required for recruitment was in the order of 100–200 seed per m^2. The most successful recruitment occurred under Ec 1, which had a seedfall of about 100 seed m^{-2} in the six months prior to recruitment. Approximately 0.7% of this seed gave rise to germinating seedlings (an estimated 161 under the tree in total) and about $\frac{1}{5}$ of these survived to the age of 3 years. Thus although 99.3% of seed which fell were lost to the system, the tree still had successful recruitment – 36 seedlings surviving and growing well after 3 years – ample to replace the tree should it die.

This seeding rate was no guarantee however, of successful seedling establishment. Other trees which had as much seedfall or more than the tree mentioned above were not nearly as successful. For example *E. caliginosa* 2 (Terrible Vale) had a similar seedfall to Ec 1 but produced only 6 seedlings, *E. melliodora* 2 (Miramoona) had twice the amount of seed but only 3 seedlings, and *E. blakelyi* 3 (Petali) produced 20 times the amount of seed and no seedlings at all. Thus successful recruitment must depend on adequate seedfall (not necessarily maximum seedfall) *in conjunction with* good rainfall and seedbed.

There is a possibility that the seed bank under *E. caliginosa* 1 was bolstered by overwintered

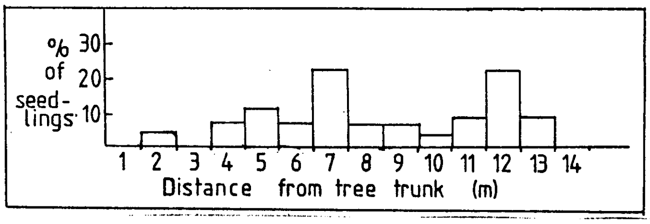


Figure 8.16: Distance from parent tree of surviving seedlings 3.2 years after recruitment – all under *E. caliginosa* 1

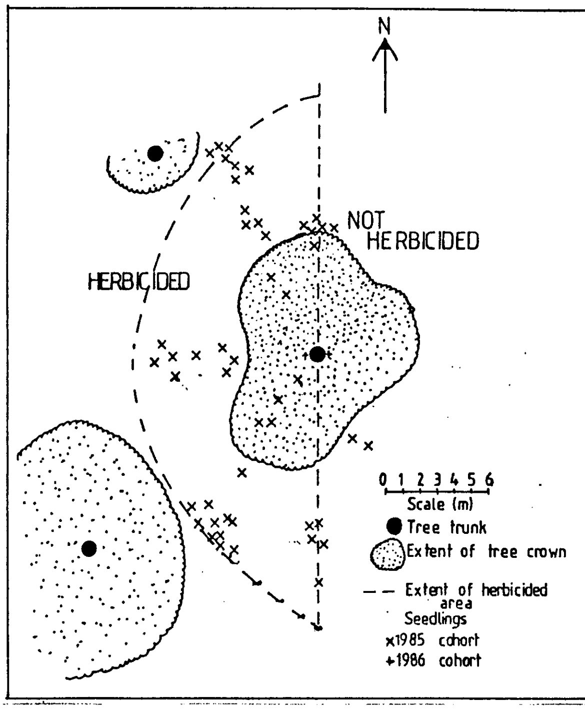


Figure 8.17: Distribution map of recruited seedlings under *E. caliginosa* 1, showing clumped pattern and that most seedlings were established on the edge of the canopy

seed or seedfall from neighbouring trees. There was no way, given the constraints of this project, that either of these factors could be measured.

Recruitment and proximity to the parent tree

The average distance (± 1SD) of recruited seedlings from the parent tree in the spring of 1985 was 4.9 ± 3.1m (Table 8.13). The seedlings which survived to the age of 3 years (all under Ec 1) were all growing on the edge of the canopy 4–13m from the tree trunk with an average distance (± 1SD) of 8.6 ± 3.1m. Very few seedlings survived closer than 4m to the trunk and none were found further than 13m away (Fig 8.16). The seedlings were clumped in small groups (Fig 8.17).

Under *E. caliginosa* 1 most seedlings alive after 3 years, were growing on the western and southern side of the tree (Fig 8.17). It is likely that this pattern of survival resulted from the better weed control on the western side of the tree due to the herbicide treatment and lower moisture stress due to shading by the parent tree and the two adjacent trees. The north–east corner had the least weed control and shading. The relative importance of these two factors could not be determined due to the lack of replication.

There is a possibility some seedlings became established from seed of the neighbouring trees, though no seedlings were found close to them.

Table 8.12: Seedfall and seedling recruitment

Tree	Seedfall: June - November 1985				Classification of seed crop §	Total number of seedling recruits spring 1985	Height of tree (m)	Area of main seedfall (m^2) ++	Number of recruits (m^{-2})	Recruited seedlings as a % of viable seed ‡	Surviving seedlings as a % of viable seed, after 3 years
	Total seed collected (Number)	Total seed + chaff collected (Number)	% of seed: seed + chaff	Total seed/m^2 +							
TREES WITH RECRUITMENT											
E. caliginosa #1 Ruby Hills	8	282	2.8	88	Heavy	161*	18	260	0.6	0.68	0.16
E. caliginosa #2 Terrible Vale	0	176	**	97**	Heavy	6	19	280	0.02	0.02	0
E. caliginosa #3 Terrible Vale					Heavy	2	16	200	0.01	-	0
E. laevopinea #1 Petali	3	55	5.5	33	Medium	2	25	490	0.004	0.01	0
E. laevopinea #2 Petali					Heavy	21	27	570	0.04	-	0
E. melliodora #1 Miramoona					Heavy	2	26	530	0.004	-	0
E. melliodora #2 Miramoona	19	1128	1.7	210	Heavy	3	21	350	0.009	0.004	0
E. melliodora #1 Petali					Heavy	14	27	570	0.03	-	0
E. stellulata #2 Birrhalee	4	48	8.3	44	Medium	14	20	310	0.04	0.09	0
E. stellulata #3 Birrhalee					Medium	2	11	95	0.02	-	0
TREES WITH OUT RECRUITMENT											
E. blakelyi #3 Petali Dam	194	1567	12.3	2144	Heavy	0	17	255	0	0	0
E. laevopinea #1 Yalgoo	0	36	**	20**	Light	0	22	380	0	0	0
E. nova-anglica #3 Yalgoo	16	85	19	177	Medium	0	15	201	0	0	0
E. nova-anglica #1 Eastlake	1	8	13	11	Light	0	12	113	0	0	0
E. nova-anglica #1 Eastlake	2	4	50	22	Light	0	16	201			
E. pauciflora #3 Yalgoo	13	159	8.2	143	Medium	0	13	154	0	0	0
E. radiata #1 Ruby Hills	36	70	51	398	Heavy	0	15 (?)	200	0	0	0
E. stellulata #1 Yalgoo	7	31	22	77	Light	0	17	255	0	0	0
E. viminalis #2 Birrhalee	5	11	45	55	Medium	0	13	150	0	0	0
E. viminalis #3 Miramoona	6	12	50	66	Light	0	25	490	0	0	0

Footnotes:

+ $Totalseed/m^2 = \frac{10{,}000n}{905}$ where n = total number of seeds collected over both seedtraps and 905 cm^2 = total area of both traps.

§Seed crop – see subsection 6.3.1

* Extrapolated backwards from 42 seedlings counted at 12 months of age, using the survival curve of a sub-sample of 46 original seedligs.

++ Area of seedfall (estimated) = πr^2 where $r = \frac{1}{2}$ the height of the tree

** Estimated by taking 5% of chaff for that period as no seed were collected

‡Recruited seedlings as a % of viable seed estimated = $\frac{seedlings\ m^{-2}}{seeds\ m^{-2}}$ x$\frac{100}{1}$

Table 8.13: Distance of recruited seedlings from their parent tree for all sites except Yalgoo and some at Petali whose parent trees were not obvious

Site	Miramoona (6a)		Birrahlee (2b)	Ruby Hills (9a)	Terrible Vale (12b)	Petali (8a)		
Species	*E. blakelyi*	*E. melliodora*	*E. stellulata*	*E. caliginosa*	*E. caliginosa*	*E. melliodora*	*E. laevopinea*	Total
Mean distance from parent tree (m)	8.0	2.6	7.1	7.1	1.4	3.0	1.8	4.9
Standard deviation	0	0.6	2.4	2.2	1.2	0.8	1.1	3.1

Seedling growth and distance from the parent tree

Seedling growth was plotted against distance from the parent tree for surviving seedlings under *E. caliginosa* 1 for 2.4 and 3.2 years after germination and a regression analysis done for each. (Fig 8.18) shows the plot at 2.4 years.

Seedlings tended to get higher, further from the tree although there was much variation. After 3 years the only seedlings surviving were 4m or more from the tree. The difference in height between these and the ones further out seemed to become less in the third year of growth, although the regression was significant at both times. Possibly the failing health of the tree meant it exerted less influence over seedling growth.

At 2.4 years the regression was of the form

$y = 28.0 + 3.63x;\ \ r^2 = 0.36$

where y = seedling height, x = distance from the tree and r^2 is the coefficient of determination ($t35 = 4.48, P < 0.001$)

At 3.2 years the regression was of the form

$y = 42.7 + 4.38x;\ r^2 = 0.19\ (t35 = 2.91,\ P < 0.001)$

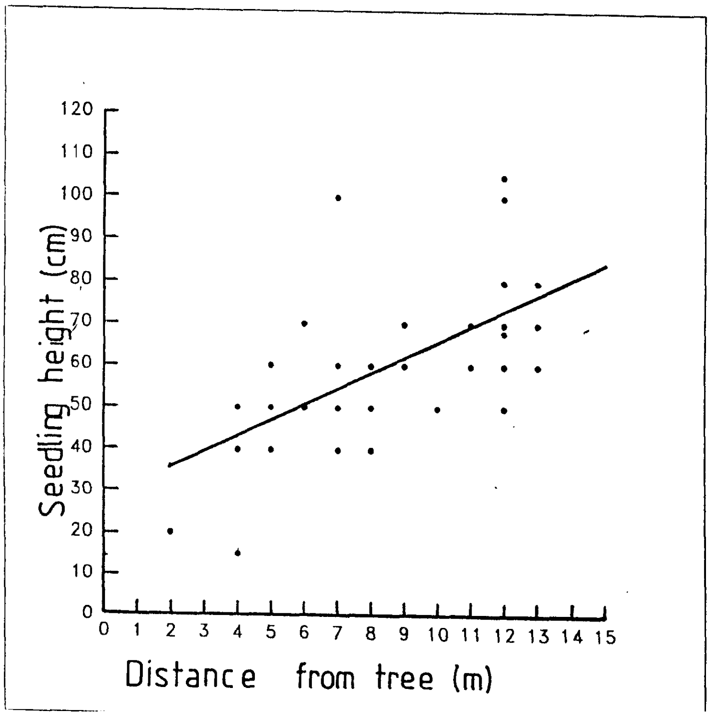


Figure 8.18: Seedling growth relative to distance from the parent tree. *E. caliginosa* seedlings under a single tree (*E. caliginosa* 1 at Ruby Hills) 2.4 years after initial recruitment. R^2 = 35.8% at 2.4 years, F value was significant at 1% level.)

Seedling growth over time

The linear form of the model ($\log y = a + bx$) was fitted to the growth of seedling height, stem diameter and lignotuber width over time for all the seedlings measured under *E. caliginosa* 1. In all cases the regressions were significant ($P < 0.001$), indicating that seedling growth for these three variables is exponential for the first three years of seedling life (Table 8.14).

Mean seedling heights were plotted against time for each variable in Fig 8.19. Although overall, growth appeared exponential with a relatively smooth curve, it was clear from observing the seedlings that growth occurred in surges – mostly in spring to early summer (ie. Nov–Dec) and autumn. Seedlings grew to about 10 cm in height in their first growing season, with a stem

Table 8.14: Linear regressions for the growth rates of seedling height, stem diameter, and lignotuber width. x = time (weeks after germination), r^2 = the coefficient of variability. See Fig 8.19 for description of lignotuber width

Variable (y)	Regression	r^2	t_{df}	Significance
Seedling height	$\log_y = 1.14 + 0.0228x$	0.76	$t_{279} = 29.78$	$p < 0.001$
Stem diameter	$\log_y = 0.0878 + 0.856x$	0.81	$t_{165} = 26.90$	$p < 0.001$
Lignotuber width	$\log_y = -1.48 + 1.22x$	0.63	$t_{165} = 16.72$	$p < 0.001$

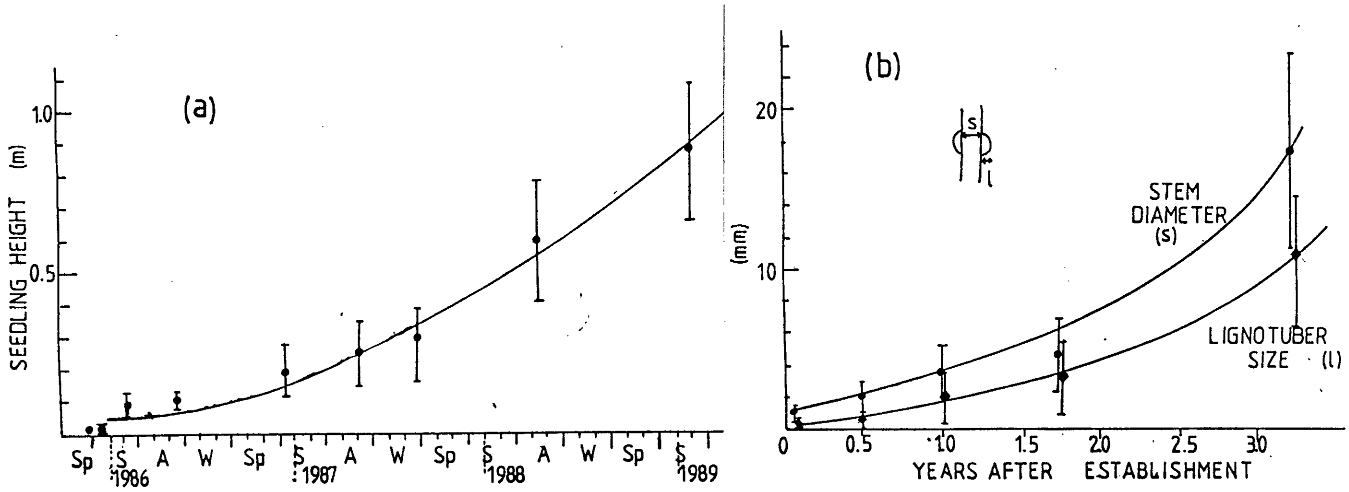


Figure 8.19: Growth of naturally recruited sedlings over time. Fig(a) shows seedling height and Fig(b) shows stem diameter and lignotuber width. Smooth curves were fitted using the formulae indicated. In each case the linear regression of log transformed data was significant ($P < 0.001$)

1–3 mm in diameter and a lignotuber about 1 mm wide. In the second season seedlings reached a height of 15–30 cm, a stem diameter of 2–6 mm and a lignotuber width of 1–5 mm . In the third and fourth seasons growth was more rapid, with seedlings reaching 40–80 cm high (mean 60 cm) by the end of the third season and 70–110 cm high by midway through the fourth season (mean of 8.7 cm). The tallest seedling after 3 full years of growth was 130 cm and 40% were 1 m or more. The mean (±1 SD) diameter of the stems was by then 17.4 ± 6.2 mm and width of lignotubers was 11.0± 4.6 mm. The thickest stem was 30 mm in diameter at ground level and the thickest lignotuber was 20 mm wide.

8.5 Growth of lignotuberous regeneration

The previous sections in this chapter examined the conditions necessary for seedling establishment of woodland eucalypts. Most regeneration programs however rely mostly on encouraging the growth of already established lignotuberous seedlings. Consequently this section describes the results of four years monitoring to compare different species and sites in their capacity to regenerate.

8.5.1 Lignotuberous regeneration: a review

Most eucalypts, other than a few of the wet sclerophyll forest species and some others, produce a lignotuber early in the life of the seedling (Plate 8.14). The lignotuber forms in the position of the cotyledonary node, developing from the accessory buds at the node, and extending eventually to encompass the other nodes at the base of the stem. Four different modes of initiation have been identified (Carr *et al.*, 1984a). In most species the lignotuber merges into the stem after the tree becomes a sapling but in mallees and some other speces the lignotuber becomes very large and remains for the life of the tree (Kerr, 1925; Mullette, 1978). This difference possibly arises from the degree of lignotuber fusion around the base of the seedling. Where fusion is complete the plant will be restrained to the form of mallee or small tree. If a zone of stem remains between non-fused lignotubers, the stem can more actively grow, forcing the lignotubers apart and forming a single stemmed tree (Carr *et al.*, 1984a).

Lignotubers consist of a mass of dormant buds and associated vascular tissues. All the elements of a normal woody stem are present (Chattaway, 1958a; Bamber and Mullette, 1978) although the sizes and shapes of the elements may be different due to the different characteristics of the lignotuber and stem cambia (Carr *et al.*, 1984a). The greater part of the lignotuber consists of tracheids and fibre tracheids, much distorted and twisted, with some vessels and parenchyma cells (Kerr, 1925; Chattaway, 1958a). In the past it was thought that the fibres, tracheids and parenchyma cells all function as storage tissue and are packed with starch while the ray cells contain protein (Chattaway, 1958b). It has since been shown that only the parenchyma cells of the rays and cortex have a storage role (Carrodus and Blake, 1970; Bamber and Mullette, 1978; Carr *et al.*, 1984a).

Concealed buds are dotted over the surface of the lignotuber in clusters or horizontal or vertical series (Chattaway, 1958a). They arise from the proliferation of accessary buds at the leaf node (Carr *et al.*, 1984a;b). The structure of the buds is similar to the concealed buds at leaf axils, having short internodes and incurving, over-arching, semi-protective leaves which open into small rounded leaves, ofter red in colour. These later give way to normal shoots of juvenile leaves and later adult foliage (Chattaway, 1958a).

The function of the lignotuber is thus a combination of storage and regeneration. The mass of dormant protected epicormic buds ensures capacity to produce shoots should the need arise, and the carbohydrate stores provide the energy for rapid shoot development. The lignotuberous seedling is typically multistemmed with 3–5, and even up to 25 stems (Enders, 1982). One interesting variation to the lignotuberous form has been found where some seedlings of *Angophora floribunda* and *E. blakelyi* were strongly stoloniferous (Enders, 1982).

Although lignotuber formation is primarily hereditory (Mullette and Bamber, 1978) considerable variation can occur in the growth of lignotubers depending on circumstances. Carr *et al.*

(1984b) found that lignotubers are suppressed by shoot growth, expand after seedling injury, and if the lignotuber is removed, seedlings can form a new one from the lignotuber cambium. Trees growing in harsh conditions may have bigger lignotubers, eg. *E. botryoides* has very large lignotubers and a mallee growth habit when growing in infertile sands (Lacey, 1983). Opinions vary on the effect of nutrients and lignotuber size. Mullette and Bamber (1978) found that increasing phosphorus levels stimulated lignotuber development in *E. gummifera*. Jahnke *et al.* (1983) found that for *E. camaldulensis*, a species in which only some provenances produce lignotubers, high levels of phosphorus had to be associated with low nitrogen for optimal lignotuber formation – high nitrogen levels led to lower rates of formation. Provenances which never produce lignotubers were unaffected by nutrition in terms of lignotuber development. Low rainfall provenances of *E. viminalis* have been found to have greater lignotuber development than high rainfall populations, while their lignotuber development was not affected by nutrient supply (Ladiges, 1974a).

Because seedling establishment is a fairly rare event for most eucalypt species (Section 8.4), the lignotuberous seedling is an important strategy for eucalypt regeneration. For example in a survey of regeneration on the Northern Tablelands, Enders (1982) found that almost all regenerating seedlings were lignotuberous and only 2 out of 780 seedlings could have been considered new recruits. Lignotuberous seedlings effectively function as a dormant *seedling* pool as an alternative to the dormant *seed* pool which many other species have as their regenerative strategy (Silvertown, 1982).

Lignotuberous seedlings can exist for many years in a forest or woodland, suppressed by the mature trees. The lignotuber allows the seedling to withstand fire, drought, insect attack, and grazing (Jacobs, 1955), and suppressed, it allows the seedling to establish a strong root system and build up food stores. Consequently once seedling release occurs (eg. after clearing or the death of a tree) growth can be very rapid and typically produces stands which are far more dense and even aged than the original forest (Chapter 2, Jacobs, 1951). Over time the saplings self thin.

It is common in woodlands, forests or paddocks to have crops of lignotuberous seedlings of different ages with lignotubers in different size classes (Enders, 1982). Regeneration usually comes from older lignotubers while younger ones wait till later (Jacobs, 1951). There is no guarantee that the regeneration will produce a stand with the same proportions of species as the original one as species have different abilities to develop persistent lignotubers (Jacobs, 1951).

Many factors affect the growth of lignotuberous seedlings, among them grazing animals, fire, weeds, mature trees, and humans. Strong links have been found between landuse and regeneration. In a survey of the Northern Tablelands in 1982 areas with pasture improvement, and fertilizer application and high grazing levels (eg. Salisbury Plans – average stocking rate of 7DSE/ha) had virtually no regeneration, while areas which were less improved and carried less stock had much more regeneration (eg. Thallgarrah sediments – average stocking rate of

3.8DSE/ha) (Enders *et al.*, 1984; Duggin *et al.*, 1986). Similarly in mid north South Australia regeneration tends to occur in areas which are not "supered" or pasture improved, and with an open woodland formation and a lower stocking rate (1.9–2.5 sheep/ha) than the usual (5–7.5 sheep/ha) (Venning and Croft, 1983; Venning, 1985a; Venning, 1988).

In pasture land where grazing is continual, seedlings are suppressed by continual minor trampling and browsing. In travelling stock reserves, where grazing is irregular but of high intensity, the damage typically consists only of broken stems (Duggin *et al.*, 1986). Lignotubers from T.S.R.'s have also been found to be in better health than those from constantly grazed areas, the latter often being badly rotted and eaten by insect lavae (Duggin *et al.*, 1986). Sheep typically do most damage to seedlings by directly grazing the foliage, while cattle tend only to trample and break the stems.

Seedlings less than 1m high are the most affected by grazing and fire, while those over 1m can usually recover (Henry and Florence, 1966; Bryant, 1971; Leigh and Holgate, 1979). On the Southern Tablelands it has been found that if grazing follows fire, growth of *E. pauciflora* seedlings is severely limited and seedling mortality is much greater than if either fire or grazing occurred alone (Bryant, 1971; Leigh and Holgate, 1979). Areas that are neither burnt nor grazed have a fairly stable seedling density with a gradual increase in seedling height (Bryant, 1971). Sub-alpine and tableland woodlands which are grazed and burnt regularly are typically grassy with few shrubs or eucalpt seedlings (Wimbush and Costin, 1979a; b; Leigh and Holgate, 1979) while cessation of grazing and burning leads to widespread tree and shrub regeneration. Wimbush and Costin (1979a) found that *E. pauciflora* seedlings mostly became established on semi-bare ground and growth slowed as herbs, shrubs and saplings competed.

Grazing also reduces diversity and growth of shrub species with understorey species such as *Acacia, Jacksonia*, Epacridaceae and Fabaceae being enhanced by stock exclusion (Cremer and Mount, 1965; Enders *et al.*, 1984; Quirk, 1985).

Shrub and tree species show a great variety in their response to both grazing and fire. Frequent burning in spotted gum-ironbark forest led to decline of spotted gum (*E. maculata*) seedlings but not grey ironbark (*E. drepanophylla*) or other associated eucalypts (Henry and Florence, 1966). On the Southern Tablelands *E. macrorhyncha* is favoured by stock over *E. melliodora*, which is in turn favoured more than *E. blakelyi* (Jacobs, 1955). In mid-north South Australia *E. leucoxylon* is relatively unpalatable to stock while *E. camaldulensis* and *Allocasuarina verticillata* are eaten (Venning and Croft, 1983). In Leigh and Holgate's (1979) trials, when eucalypt seedlings were cut above the lignotuber they mostly recovered whereas none recovered if cut below the lignotuber. However a second defoliation caused substantial deaths in *E. mannifera, E. macrorhyncha* and *E. polyanthemos* while *E. melliodora* and *E. bridgesiana* survived. *E. blakelyi*, *E. nortonii* and *E. macrorhyncha* showed some resistance to burning. Differential responses to grazing in shrubs to burning and/or grazing have been reported by Cremer and Mount (1965), Leigh and Holgate (1979), and others.

Bryant (1971) recommended complete exclusion of sheep for 5–7 years in subalpine communities to allow seedlings to get established enough to withstand grazing or fire. There is no doubt that exclusion of stock frequently leads to recolonization by eucalypts and other native trees and shrubs and there are many examples where this has occurred (eg. Jacobs, 1951; Pratten, 1984). However complete exclusion may not always be necesary to get regeneration. For example in mid north South Australia it has been found that as long as stocking rates are low (less than 0.5 sheep/hectare) regeneration could occur (Venning and Croft, 1983; Venning, 1985a; Venning, 1988). In pine forests in the United States, cattle are allowed to graze in the summer when they do not do much damage to the trees, but not in spring, when the conifers are actively growing. The grazing increases tree growth by reducing competing vegetation (Wood, 1972; Hederick, 1975; Cleary, 1978). There are few similar reports in Australia. Dexter (1967) reported that *E. camaldulensis* seedling growth was enhanced by cattle grazing competing vegetation and Burrows (1981) reported on cattle being used in a pine plantation in Western Australia to reduce grass growth but did not mention the effect on trees. Duggin *et al.*(1986) reported that cattle damage was worse in the late autumn to winter months when fodder declined and they grazed more intensively around the saplings and sought more shelter.

E. pauciflora seedlings have greater digestibility and nitrogen levels in summer than in winter and higher levels of both in regrowth foliage after fire and insect attack than mature foliage (Leigh and Holgate, 1979). Thus seedlings may be more attractive (and hence vulnerable to livestock in spring/summer than winter.

On the Tablelands it is possible that light grazing (less than 0.5 sheep per acre) in combination with annual cool winter burns may have increased the amount of regeneration in the 1870s to 1920s, as well as encouraging unfavourable grass species such as *Aristida* spp.

Competing vegetation can inhibit regeneration of lignotuberous seedlings. Lantana smothers regenerating seedlings in spotted gum-ironbark forests (Henry and Florence, 1966) and Wimbush and Costin (1979a) reported that *E. pauciflora* regeneration slowed as herb and shrub growth competed. In alpine country Noble (1980) reported that *E. pauciflora* seedlings less than 4 cm from tussocks of snow grass suffered high mortality because of competetive effects. However seedlings which were 4–8 cm from the tussock benefitted from the protection provided by the grass. Seedlings further away grew more vigorously but suffered more frost damage. Mature eucalypts themselves can significantly inhibit regeneration. Henry and Florence (1966) reported that lignotuberous growth was greatly inhibited by mature trees. Suppression was evident up to a distance of 15 m from the stand and they suggested that a canopy gap of about 30m in diameter was needed for unimpeded growth and a larger gap was needed to get a uniform group of regrowth saplings. Lignotuberous seedlings could stay in a static equilibrium for up to 15 years at least, and once the canopy was removed there was an immediate response. Duggin *et al.* (1986) found similar suppression in stringybark forests of the Tablelands. Whereas there was vigorous regrowth in non-forested sites from 1982–1985, there was little growth of seedlings in forested sites (the vigorous growth in pastures and T.S.R.'s was due to low stocking rates and

Table 8.15: Numbers of lignotuberous seedlings monitored in detail at each site.

SITE:	Eastlake (Site 3a))			Petali Dam (Site 8a)		Petali House (Site 8b)		Terrible Vale (Site 12a)			Yalgoo (Site 16a)	Total
SPECIES:	*E. blakelyi*	*E. laevopinea*	*E. melliodora*	*E. laevopinea*	*E. melliodora*	*E. blakelyi*	*E. melliodora*	*Acacia dealbata*	*Jacksonia scoparia*	*Eucalyptus pauciflora*	*E. laevopinea*	
NUMBER OF SEEDLINGS:	5	5	5	7	4	10	13	20	20	20	58	167

low population of leaf eating insects following the 1982 drought).

In alpine ash forests in Tasmania, Bowman and Kirkpatrick (1986a;b) decided that supression by mature trees was mostly due to their competiveness for moisture, and allelopathic and nutrient factors were only slightly involved. Some suppression by frost in the gaps was also evident.

Given the importance of lignotuberous seedlings in natural regeneration a number of sites were examined to elucidate the factors influencing their growth and survival in grazing lands of the Northern Tablelands.

8.5.2 Methods

Twenty four of the sites described in Appendix VII were examined in this regeneration study. Each was described according to existing vegetation, pasture type, tree and shrub density, soil, geology, aspect, topography and history (Chapter 5). Measurements of density and mean height were made of regenerating trees and dominant shrubs such as *Acacia* species, in 1985 and again in 1988. At five sites, where regeneration was evident in 1985, 5–20 specimens of each species was tagged with plastic flagging tape and measured 1–2 times each year (Table 8.15) – 167 seedlings in total. It was not possible to get even numbers of seedlings as some sites had too little regeneration. Similarly the constraints of the project made replication of sites difficult.

At three sites (Petali Dam, Terrible Vale, Yalgoo) grazing was stopped at the beginning of the study and seedlings were quite small at that stage (< 30cm). At Eastlake grazing had been excluded 2 years before monitoring commenced and at Petali House grazing had been at a low level for many years prior. At both of these sites seedlings were well established and up to 1m high when observations began.

8.5.3 Results

Survival amongst the established seedlings was very high. Of the 167 seedlings monitored, only 8 died in the three years of observation (95% survival). This is in accord with section 8.4 where low mortality was found in seedlings of over one year's age. In all cases the seedlings measured in this part of the trial were well established prior to observation.

Seedlings at Eastlake (*E. blakelyi*, *E. laevopinea*, *E. melliodora*) grew only slowly over time. The same pattern was apparent at Petali and Yalgoo where overall height increases were only 10–30cm in three years (Fig 8.20). The contrast between these sites and Terrible Vale was extreme. At the Terrible Vale site seedlings grew from 10 cm high on average to over 2m in

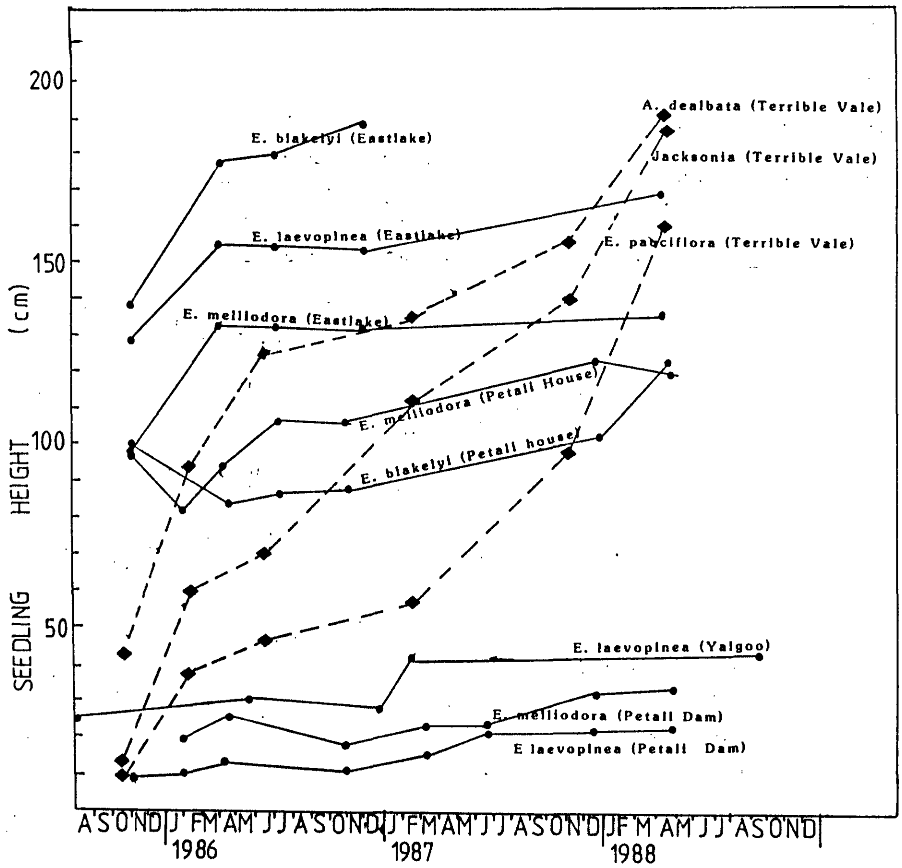


Figure 8.20: Growth of lignotuberous seedlings at 5 sites. Each species is marked separately. Mean height of each sample is plotted (see Table 8.15).

three growing seasons. The three dominant species (*E. pauciflora*, *Acacia dealbata, Jacksonia scoporia*) all grew equally well.

It is difficult, given the limitations of the data, to isolate specific causes of the differential growth between sites. Geology was similar at all sites – they all being meta-sedimentary. Pasture growth was different at the sites and may have contributed to the growth differences. Terrible Vale was completely native pasture, being dominated by *Poa sieberana* and *Themeda australis*, while other sites had natural pasture with a mixture of native perennials and exotic annuals. Seedlings at Petali Dam had little obvious competition from grass in some places where there was much bare ground, but much of the site was dominated by annuals such as *Bromus molliformis, Hordeum leporinum, Vulpia bromoides*, and *Cirsium bromoides* and perennials such as *Danthonia* spp. Yalgoo had a thick sward of *Microlaena stipoides* and *Poa sieberana.* At Eastlake there was a thick sward of grass dominated by *Stipa* sp, *Poa sieberana* and *Miciolaena stipoides* and other native species and at Petali House the sward of grass was dominated by *Bromus molliformis, Poa sieberana, Vulpia* sp and *Lepidium hyssopifolium.*

Timber density may have been an important factor influencing regrowth. Terrible Vale had a density of only 17 trees per hectare, while Petali House had 28, Petali Dam had 45, Eastlake had 27, and Yalgoo had 342 trees per hectare. Suppression of seedlings by mature trees was observed in section 8.4 and is likely to be a factor here, at least at the Yalgoo site, if not at the others.

In addition *A. dealbata, Jacksonia scoparia* and *E. pauciflora* all have a great capacity for rapid growth following exclusion of stock. In the case of *E. pauciflora* this rapid growth has been observed by Enders (pers.comm.) on a travelling stock reserve near Aberfoyle, where *E. pauciflora* seedlings grew from less than 50cm high on average to 1–5m high from 1982 to 1989 and about 50% of the seedlings were 2–5cm tall after 7 years growth. Although most of this regeneration was in a gap in the woodland, seedlings also grew well amongst the trees (a woodland with a density of 100–150 trees per hectare).

It seems likely that a combination of low timber density, native grasses with less competitive effects and the species association all contributed to the rapid regeneration of Terrible Vale. The fact that it was very rocky with a poorly developed lithosol soil could also have been relevant.

Table 8.16 shows the changed height and density of regenerating seedlings at the 24 sites examined, following the exclusion of grazing. There were not enough sites to perform a statistical correlation incorporating all factors however a clear impression of sites which have a high or low capacity to regenerate could still be formed from the information gathered.

The best indicators for whether or not regeneration is likely were the presence or absence of shrubs, pasture type and the presence or absence of trees. Soil type, health of existing trees, tree density, community and (to a lesser extent) species association, all helped in predicting regenerability of a site, while aspect and geology gave little information in this regard.

The density of shrubs gave a clear indication of the level of regeneration. Where shrub density was very low there was little regeneration. Pasture type was also very relevant. The more improved the pasture, the less regeneration was evident. Interestingly at Birrahlee (2b) which was a pasture dominated by *Festuca arundinacea* and *Cirsium vulgare* a small amount of regeneration occurred in places. Tree density was related also. No regeneration occurred in the absence of trees. Regeneration was good as long as density exceeded 25 trees per hectare. A high density of trees (ie. 300–400 trees per hectare) did not necessarily lead to much regeneration of eucalypts although dense regeneration of acacias and other shrubs occurred at both such sites. Regeneration tended to be better when tree health was good and where trees were in poor health there was less regeneration. However good tree health did not necessarily lead to good regeneration – eg. if there was highly improved pasture the presence of healthy trees did not ensure regeneration.

Soil type was related to regeneration in that the better soils had been more cleared and improved and hence had less regeneration than the gravelly rocky soils. Position on the slope and slope were the same in that regeneration tended to be higher on upper slope and steeper positions while the lower slopes, flats and gently sloping country had little regeneration, except at one site which bordered a creek. Again the flats tended to be more intensively developed than the stoney ridge tops.

Community and association seemed partly related to regenerability of a site. Sclerophyll scrub forest, grassy sclerophyll forest and tall woodland all tended to have regeneration while

Table 8.16: Regeneration at 22 sites within a 90km radius of Armidale, following the exclusion of grazing. For an explanation of the codes see below

Site	Regen density 1985 No./ha	Regen density 1988 No./ha	Regen ht 1985 (m)	Regen ht 1988 (m)	Tree condition	Tree density (per ha)	Shrub density (per ha)	Com-munity	Assoc-iation	Pasture	Geology	Soil	Position on slope	Slope (°)	Aspect
Regeneration absent															
Belhaven (1a)	0	0	-	-	0	0	0	Is trees	Em/Eb	Natural	Gran	2	4	3-4	S
Newholme (7a)	0	0	-	-	1		0	Gr.Wood	Em/Eb	Improv	Gran	3	4	5-6	N
Ruby Hills (9b)	0	0	-	-	0	0.5	0	Grass	Ena/Es	Improv	Sed	10	2	1	N
Terrible Vale (12b)	0	0	-	-	3	27	0	Gr.Wood	Ec	VImpr	Sed	9	5,6	7-10	S,W
Woodpark (15a)	0	0	-	-	1	IsClump	0	Is trees	Em/Eb	Natural	Sed	2	3,4,5	2-5	N,W
Yalgoo (16b)	0	0	-	-	3	47	0	Gr Wood	Ep/Es Ena	Improv	Sed	2	3	2	E
Regeneration low															
Belhaven (1b)	0	3	0	0.3	3	0.5	0	Is Trees	Eda	Native 2	Bas	4	4	2	N
Birrahlee (2b)	0	2.6	-	1	2	48	6	Gr Wood	Ev/Es	VImpr	Sed	3	4,5,6	2-5	S,W
Miramoona (6a)	0	4	0	0.5	2	50	0	Is clump	Em/Eb	Improv	Sed	1	6	1-2	E,W
Miramoona (6b)	0	4	0	0.5	3	9	0	Is clump	Ev	Improv	Sed	?	4,5,6	5	E,S
Salisbury (10)	0	1	-	-	1	6	0	Open Wo	Em/Eb	Natural	Sed	1	5,6	2	E,W
Yalgoo (16c)	0	1	-	-	3	53	0	Is clump	Ena	VImpr	Sed	2	3	1-2	E,S
Regeneration moderate															
Eastlake (3a)	Very sparse	35	0.5	0.5	3	27	19	Gr Wood	Em/Eb, Ec	Native 2	Sed	1	4,5,6	15	N,W
Eastlake (3b)	?	23	0.3	0.5	3	89	9	Gr Wood	Ep/Ena	Natural	Sed	?	4,5,6	2-3	W
Europambela (4b)	0	25	0	1	3	23	18	Is clump	Ev	Natural	Sed	7	4,5,6	7-10	N,S,E
Newholme Creek (7b)	sparse	sparse	?	?	3	sparse	0	Gr Wood	Ena	Native 2	Gran	3	1-2	2	W?
Petali (8a)	Very sparse	10	0.1	0.3	3	45	23	Tall Wood	Em/Eb	Natural	Sed	1	4,5,6	5-10	W
Petali (8b)	Is.clump	?	0.5	1	3	28	0	Gr Wood	Em/Eb	Natural	Sed	1	4	6	E
Ruby Hills (9a)	Isolated	11	0.2	1.5	4	444	122	Gr Sc For	Ec/Er	Natural	Sed	7	4,5,6	1-7	W
Regeneration high															
Birrahlee (2a)	dense	167	1	1	3 or 4	292	5000	SclShWo	Ep	Native 1	leuco	8	5,6	5-10	S,E,W
Europambela (4a)	sparse	sparse	-	-	5	mid-dense	dense	SclShWo	Er	Native 1	Sed	7	3,4,5,6	1-50	W
Terrible Vale (12a)	2	220	-	-	3	18	325	Is trees	Ep	Native 2	Sed	7	5,6	18-20	W
Woodpark (15b)	dense	dense	-	-	2	sparse	sparse	Gr Wood	Em/Eb	Natural	Sed	2	3,4,5,6	2-5 15	N,E
Yalgoo (16a)	400	500	0.2	1	3	342	51	GrScFor	El	Native 2	Sed	9	4,5,6	2-8	N,S,E,W

Association

- Eb *E. blakelyi*
- Ec *E. caliginosa*
- Eda *E. dalrympleana*
- El *E. laevopinea*
- Em *E. melliodora*
- Ena *E. nova-anglica*
- Ep *E. pauciflora*
- Er *E. radiata*
- Es *E. stellulata*
- Ev *E. viminalis*

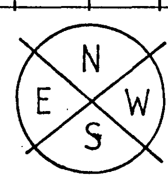
Community

- Gr Sc For Grassy Schlerophyll Forest
- Tall Wood Tall Woodland
- Gr Wood Grassy Woodland
- Scl Sh Wo Sclerophyll Shrub Woodland
- Subal Wo Subalpine Woodland
- Scrub Scrub
- Grass Grassland
- Open Wo Open Woodland
- Is Trees Isolated Trees
- Is Clump Isolated Clumps of trees

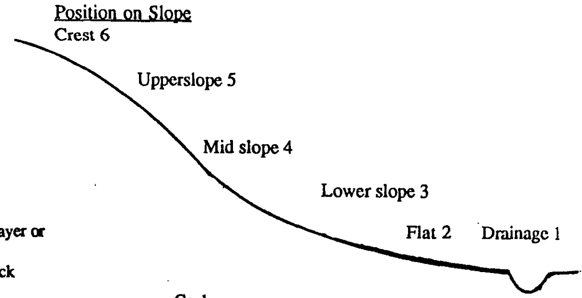
Soil

1. Red/Yellow Podzolic
2. Lateritic Podzolic
3. Grey/Brown Podzolic
4. Chocolate
5. Prairie
6. Gravel
7. Lithosol
8. Sand
9. Yellow Earth
10. Gley Podzolic

Aspect



Position on Slope



Trees Condition

- 0 No (or virtually no) trees present
- 1 Most trees in poor health
- 2 About half trees in poor, half in good health
- 3 Most trees in good health
- 4 Half trees in good, half in very good health
- 5 Most trees in very good health

Pasture

- Native 1 Native grasses, extensive litter layer or bare area.
- Native 2 Native grasses in sward or tussock grassland.
- Natural - either one which was a reverted improved pasture consisting primarily of native and/or naturalized grasses, or a native pasture containing some exotic, naturalized, pasture species.
- Improv Improved pasture - one which contains mainly sown species, plus a variety of species other than those which were sown.
- VImpr Highly improved pasture - one consisting primarily of sown species.

Geology

- Sed Sediments
- Bas Basalt
- Bas col Basalt colluvium
- Gran Granites
- Leuco Leucodamellite

Density - See Table 5.2.

FOR EXPLANATION OF TERMS SEE CHAPTER 5

grassland had no regeneration. However grassy woodland, isolated trees or clumps of trees or green woodland all had varying degrees of regeneration, depending on other factors such as pasture type, presence of shrubs, position on slope etc. Some associations were commonly associated with regeneration such as *E. radiata*, *E. pauciflora*, and stringybark, while *E. blakelyi*, *E. melliodora*, *E. nova-anglica*, and *E. viminalis* tended to be associated with low regeneration. *E. pauciflora* produced the fastest growing regeneration than any other association. Again, this seemed to be related to level of improvement – eg. stringybark and snow gums commonly occupy the stoney hills which are less intensively mangaged while the *E. blakelyi* /*E. melliodora* association commonly occurs in a mid slope position on better soils, which are more intensively managed.

Most of the sites occurred on sedimentary rock. It was clear that one type of rock can give rise to a big range of regeneration depending on other conditions, such as position on slope, soil, pasture type etc., and geology alone is no indication of the degree of regeneration possible. Aspect was completely unrelated to regeneration.

In conclusion regeneration was at its best at sites which had the following characterisitcs: steep, poor soil (eg. lithosols or sandy soils), upper slope position, native pasture, shrubs and trees present and in reasonable health. In contrast regeneration was absent or low in places where trees and shrubs were absent or in very low densities, dieback was prevalent, and the pasture was improved. In most cases this tended to be where the soil was more fertile, in lower slope position in gently sloping country. In other words the degree of regeneration was related to the intensity of the land management.

There was little doubt that at all sites regeneration had been suppressed by grazing and was released once sheep or cattle were excluded from the site. The most spectacular example of this was Terrible Vale (12a). It is possible that a certain level of grazing can accompany regeneration. At Petali House the paddock was grazed very lightly with a few cattle. They broke and trampled some seedlings but did not greatly interfere once the seedlings were over 1m high.

8.6 General Discussion - Seedling establishment

The trials reported in this chapter describe all the main factors influencing eucalypt seedling establishment on the Northern Tablelands. The depth of sowing trials found that the optimal depth for sowing eucalypt seeds is 2–4mm, with reasonable emergence up to 14mm and very little emergence from deeper than 15mm. These results parallel those of Cremer (1965b), Ashton (1979), Free (1951) and Agar (1984), who all found very little emergence from eucalypt seeds buried deeper than 15 mm. Although the species examined had the potential to produce shoots 20mm long, and occasionally 30mm (Section 8.1), the soil prevented all but 5% of seedlings emerging from depths greater than 18mm. This contrasts with grass seeds which have great capacity to emerge from depth; even small ones the size of eucalypt seeds have been found to emerge from up to 50mm depth (Watt and Whalley, 1982a,b). Surface sown seeds (Section 8.3) did not lead to good seedling establishment, probably due to desiccation of seeds, as also found by Free (1951). In the natural situation (Section 8.4), seed must get buried by rainfall and litter.

The pot trial, recruitment trials, and actual observations of natural recruitment all confirmed that an average of about 25mm of rain per week over the first 3 months of establishment is necessary for successful recruitment. The average rainfall for Armidale from September to February is about 17mm per week, which is probably too low for successful recruitment. The observations of actual recruitment at Ruby Hills (Section 8.4) suggest that 1.5 times the average is necessary. Establishment was favoured by drizzly, continual (not necessarily heavy) rainfall, rather than heavy rain events punctuated by long hot, dry periods. The first three months is critical and if seedlings can get well established in this period they can sometimes survive dry periods following. Venning and Croft (1983) and Venning (1985a) also found that seedling recruitment was favoured by summer rainfall well above the average. The results of sections 8.3 and 8.4 imply that recruitment can occur in this area in spring or autumn as long as rainfall is adequate. Most recruitment probably occurs in spring although in the wet autumn of 1983 which had double the average rainfall (20 mm per week from March to June compared with an average of 10 mm per week) I observed newly recruited *E. caliginosa* seedlings in Eastwood State Forest and *E. blakelyi* seedlings near the Gwydir River - both in native pasture and in naturally clear areas of the woodlands. Autumn germinants would have the disadvantage of being very small and hence suceptible to winter frosts, which Baker and Grose (1961) found accounted for very high mortality in *E. delegatensis*.

Nadolny (1984) compiled rainfall records of the last five decades. Wet spring/summers (Dec/Jan) like the 1985/86 season have happened 7 times in the last 48 years (1947/48, 1955/56, 1959/60, 1970/71, 1975/76, 1985/86, 1988/89) – two of these events occurred within this study period. Very wet autumns have occurred twice (1977, 1983). Thus seasons when recruitment is possible occur, on average, every six years in this area. However this does not necessarily mean recruitment happened at these times. The high rainfall summers in 1970/71 and 1975/76 coincided with bad dieback (Nadolny, 1984) (indeed were partly responsible for it - Chapter 3) which would have affected the seed crop sizes (Chapter 6.4). As was found in 1988/89 a dense sward of grass around trees at the time of the good rain will also inhibit recruitment (Section 8.4).

Enders, in his survey of lignotuberous seedlings on sites with a history of grazing, found two, and sometimes three, distinct size classes. He suggested that seedling recruitment took place prior to the 1965 drought, just following that drought, and at the onset of drought conditions in 1979 (Enders, 1982; Duggin *et al.*, 1986). Between the droughts were moist years when stocking rates were high, regeneration was suppressed and dieback was sometimes severe. During the droughts however suppression by stock and pasture was less, allowing regeneration to grow. Insect attack is substantially reduced in drought (Nadolny, 1984) and trees can therefore produce higher fruit crops following them (Chapter 6).

The weather and dieback information of Nadolny (1984), the studies of lignotubers by Enders (1982; 1989) and my studies on recruitment and flowering can now be combined to produce a likely picture of dieback and regeneration on the Northern Tablelands over the last 30 years (Fig 8.21).

The lignotuberous seedlings observed by Enders in 1982 were possibly mostly recruited in the moist summer of 1970/71. As he says these were probably suppressed over the 1970's and were able to get away in the 1979-82 drought. The earlier period of recruitment (probably coinciding with the 1959/60 moist summer, would have grown during the 1965 drought and led to the sapling stands which in the bad dieback years of the 1970's were severely affected. The 1970/71 recruitment which grew well in the early 1980's has been badly damaged by insect attack over the last three summers which could severely affect regeneration in some areas.

In 1982 Enders measured lignotubers at one site which were 0.5g in weight (approximately 5mm wide) and which he suggested were probably recruited in the lead up to the 1979 drought. Based on the growth rates of lignotubers I observed (Section 8.5) they were probably 2 years old when he saw them. They may have been recruited in the moist autumn of 1977, or alternatively in 1978-80 if there was localized high rainfall (more than the general pattern at the time).

The recruitment trials and observations all confirmed the results of Dexter (1967), Floyd (1960) and Baker and Grose (1961), that the seed bed has to be clear of competing weed growth.

In forests, burning is frequently used to stimulate seedfall and provide a good seed bed and to encourage regeneration (Cremer, 1971; Purdie, 1977a,b). On the Tablelands this may have been the way natural regeneration was stimulated prior to European colonization, although I have observed recruitment in naturally clear areas in unburnt grassy woodlands (see above). It may be possible to encourage recruitment through the use of fire, perhaps in early spring or late summer when the grass sward is dry and there is the possibility of good rain. However, as reported in Chapter 9, burning pasture can lead to a massive invasion of weeds such as thistles, and would only give satisfactory results in completely native pasture. The use of contact herbicides can create a weed free zone near trees for long enough to stimulate recruitment. It has been used successfully in Victoria where small areas under big, fruiting *E. camaldulensis* trees have been sprayed with contact herbicides such as Roundup or Sprayseed in late winter or early spring (Farm, 1986b; Lawrence, 1985) and recruitment has resulted. Additional cultivation in the autumn before can also help. My results confirm that this technique can be successful on the Northern Tablelands. If herbicides are used possibly the best program would be to spray Roundup in early spring to kill the first germination and again in mid spring to kill the second germination. An alternative might be to burn late winter and spray mid spring.

Because of the danger of herbicide damage to the tree, and because there is little regeneration close to the trunk, spraying should be no closer than 5m to the tree. It could extend to $1–1\frac{1}{2}$ times the height of the tree away from the tree as that is the average distance of seed dispersal (Chapter 6), although my results suggest that most recruitment occurs 5–15m from the trunk of a 20m size tree.

Success is more likely in the area which receives shade from the tree - that is the southern, eastern and western sides of the tree - not the northern aspect. The area to be regenerated could be a ribbon around the edge of the canopy, or a block. The Potter Farmland Plan used octogon shaped blocks (Farm, 1986b).

The use of the other herbicides such as Vorox AA, Roundup, Sprayseed and Simazine have been used in South Australia to encourage regeneration of native pines and acacias. Small seedlings were released from the competitive pasture by spraying in May-July (Farm, 1986a; Venning, 1988).

In Victoria some areas are prepared for natural recruitment by cultivating the soil first (Curtis and Reeve, 1988b). On the Tablelands this technique may be suitable for stoney or poor soils which support native pasture, and where there are healthy fruiting trees present.

Recruitment is only likely when trees have good crops of seed. As found in Chapter 6.4, bad dieback suppresses flower bud formation and fruit production and so in badly affected dieback areas, recruitment from seedfall is rare. This factor, combined with weather, pasture, and stock, further limits when seedling recruitment is possible, and in the last 30 years there has possibly been only 5 seasons when recruitment occurred, and probably only 2 seassons when recruitment was widespread. Conceivably, like seedbeds, seed crops could be manipulated by sowing seed or laying brush containing seed bearing capsules on a properly prepared area.

The pattern of distribution of seedlings is determined by the distance seeds fall and the parent tree itself. There is a clear indication from my results that the parent tree helps young seedlings by providing shade and hence protection against frosts and dry weather (also found by Bowman and Kirkpatrick, 1986b, in *E. delegatensis* forest). On the other hand the mature trees suppress seedlings if they were too close (also found in ironbark forest by Henry and Florence, 1966). The most likely cause of this suppression is competition for moisture (Bowman and Kirkpatrick, 1986a,b), although allelopathic reactions may also be involved (Lovett, 1986). Thus eucalypt seedlings do not get established very close to the parent tree or very far away and the result is a pattern of regeneration of clumps around existing trees, which over a long time would slowly expand, given the right conditions. Examples of this clumping pattern are quite common on the Northern Tablelands.

Lay (1985) found a similar pattern of natural regeneration in a planted woodland in the Adelaide Hills. Regeneration formed in the "halo" of grass suppression near trees but outside the actual canopy, while virtually no seedlings occurred actually under the canopy or outside the halo. Average distance from the parent tree of seedling was 2.8m, average height of trees being 6–9m and 8–10 years old.

Eucalypt seedling survivorship (sections 8.3, 8.4, 8.5) follows the classic Deevey Type III curve, which is the typical recruitment pattern for trees (Silvertown, 1982). Lodge (1981) found a similar pattern in grasses. About 0–0.7% of seeds germinate. Of these there is massive mortality in the first few months, largely due to desiccation or weed growth. A success rate of

20% of emergent seedlings would be regarded as high.

The growth of the lignotubers which I measured was slower than those measured by Henry and Florence (1966) in ironbark spotted gum forest which grew to about 25mm in 15 months.

My measurements of seedling growth implied a dormant period in winter, with most growth in the spring and summer. Although the measurements were not as frequent as those of Duggin *et al.* (1986) they confirmed their results, that regenerating trees have vigorous growth in mid-late spring, and again in the late summer autumn period. They also mention that strong growth is usually accompanied by shedding older leaves, and bark is shed in the summer or autumn growth period.

There was little doubt from my results that exclusion of stock enhanced regeneration of eucalypts and native shrubs. At virtually all the sites regenerating trees and shrubs were very small or not evident before exclusion and grew once the stock were kept out. However stock exclusion did not necessarily lead to vigorous seedling growth as pasture growth, insect attack, and mature trees could all inhibit growth.

Natural regeneration is most likely where there is relatively intact forest or woodland which has native pasture and shrubs present. It is next most likely where there are isolated clumps of trees or isolated trees or open woodland, where there is native pasture and shrubs. Such places where regeneration is more likely are commonly found on rock hills, steeper areas, with poorer soil. It is less likely where the woodland or clumps of trees growing in improved pasture, particularly if the trees are unhealthy. There is virtually no possibility of regeneration where there are no trees, no matter what type of pasture. Plates 8.15 to 8.21 show the range of regeneration possible at different sites.

These results of mine corresponded to those of Duggin *et al.* (1986) and Venning (1988), who have surveyed regeneration in grazing areas. Wimbush and Costin (1979a,b) also found no regeneration in alpine country where there was extensive death of *E. pauciflora* trees, farm grazing or fire due to lack of seed. Regeneration was also restricted where there was a dense herbaceous understory, except in localized patches of bare soil.

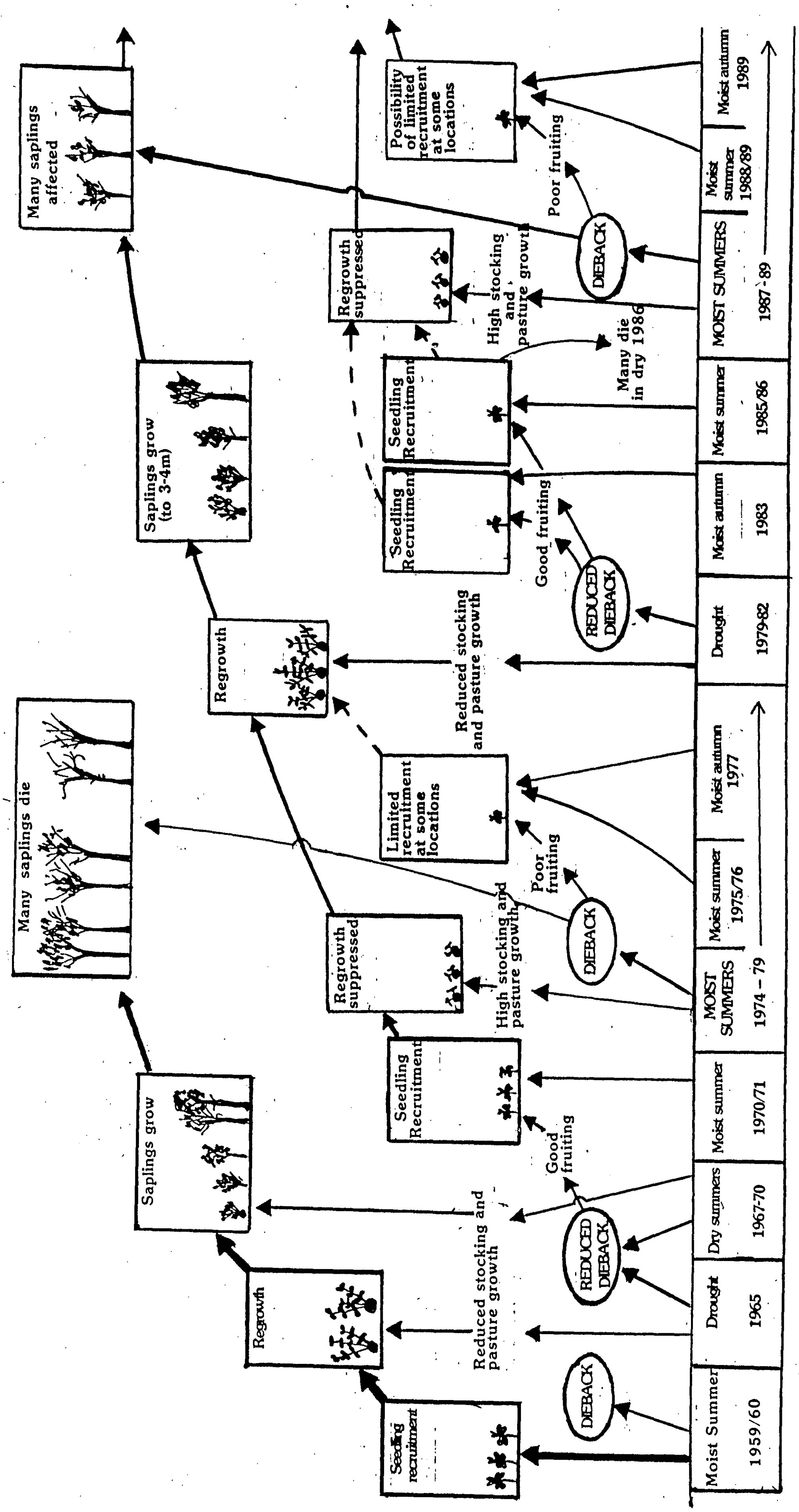


Figure 8.21: Proposed regeneration and dieback history over the last 30 years on the Northern Tablelands.

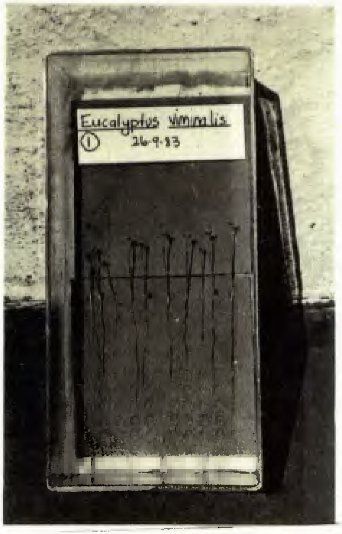


Plate 8.1 Seedlings of *E. viminalis* in a petri dish after being grown in the dark at a constant temperature of 25°C for 14 days.

Plate 8.2
Depth-Moisture Trial
Watered every 2 days,
Depths 2-23 mm.
13 Sept 83 - 3 months after sowing.

Plate 8.3
Depth-Moisture Trial
Watered every 7 days
Depths 2-23 mm.
13 Sept 83 - 3 months after sowing.

Plate 8.4 Site of recruitment trial - looking north at the "tree plots" from the open plots December 1982.

Plate 8.5: Mulched, burnt, watered plot. November sowing. *E. viminalis* seedlings $1\frac{1}{2}$ months after sowing (Dec. 1982).

Plate 8.6: Same treatment as Plate 8.5, 1 year after sowing (Oct 1983). Phalaris is thick all around the plot but has not penetrated the mulch. Seedlings are about 10 cm high.

Plate 8.7: Mulched, grass treatment, autumn sowing, on edge of trees. 7 months after sowing (Oct 1983). Behind it can be seen an unmulched, grassy plot. Weeds grew in the gaps provided to sow the seeds but not through the mulch itself.

Plate 8.8: Recruited *E. laevopinea* seedling, 4 months old, showing method of tagging. 5 Feb 1986 Yalgoo (site).

Plate 8.9: *E. stellulata* seedling three months after germination. Birrahlee (site 2b), 20 Feb 1986.

Plate 8.10: Recruited seedlings (marked with a stake) under *E. caliginosa* at Ruby Hills (Ec 1). 2 months after recruitment weed growth had returned but did not dominate 12 Feb 1986.

Plate 8.11: Recruited seedlings marked with a stake under *E. caliginosa* at Ruby Hills (Ec 1), spring two years after recruitment. Grass sward germinating normally. 12 Nov 1987. Pattern of seedling establishment shown by stakes.

Plate 8.12: Recruited seedling under *E. caliginosa* at Ruby Hills (Ec 1), two years after recruitment. 12 Nov 1987.

Plate 8.13: Recruited seedlings under *E. caliginosa* at Ruby Hills $3\frac{1}{2}$ years after recruitment. Feb. 1989. The decline of tree health is evident.

Plate 8.14: Young Lignotuberous seedling of *E. melliodora*.

Plate 8.15: Dense regeneration of *E. pauciflora*, *Leptospermum brevipes* and various other shrubs at Birrahlee (2a) following fencing in 1984. Grazing prevents regeneration spreading outside the fence.

Plate 8.16: Dense regeneration of *E. blakelyi*, *E. melliodora*, *E. viminalis*, and *Angophora floribunda* at Woodpark (Site 15b) in Sept 1983 following exclusion of stock 3 years earlier. Grassy woodland, severely affected by dieback. Natural pasture. Regrowth has been slow to grow, possibly due to grass competition and insect attack.

Plate 8.17: Dense regeneration of *E. pauciflora*, *Acacia dealbata*, *Jacksonia scoparia*, Terrible Vale (Site 12a), April 1988. Rocky hill, native pasture, isolated clump of trees. Regrowth followed fencing in 1985.

Plate 8.18: Same site as Plate 8.18. How the site was before exclusion of grazing.

Plate 8.19: Dense regeneration of *E. laevopinea* and *A. dealbata* at Yalgoo (Site 16a) Jan 1988, following exclusion of stock in 1985. Grassy sclerophyll forest, native pasture, rocky hill. *E. laevopinea* seedlings suppressed by trees, shrubs grown well.

Plate 8.20: Scattered regeneration of *E. viminalis* at Europambela (Site 4b), April 1988, after exclusion of stock in 1984. Isolated clump of trees on rocky hill, natural pasture.

Plate 8.21: Sparse regeneration of *E. stellulata* at Birrahlee, April 1988 after exclusion of stock on 1985. Improved pasture, scattered seedlings in 'halos' of some of the clumps of trees.