Some Silvical Characteristics and Notes on the Silviculture of Alpine ash, Eucalyptus delegatensis

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INTRODUCTION

Eucalyptus delegatensis, one of the «ash» group of renantherous eucalypts, is indigenous to south-eastern Australia. In the Victorian highlands its optimum altitudinal range is from 3,300-4,500 feet, with extremes of 2,400 and 5,200 feet above mean sea level, while in Tasmania it is common at altitudes of 1,000-3,000 feet. Annual rainfall in its habitat ranges from about 40-90 inches, winter snow included. Additional precipitation in the form of fog drip is likely to be considerable as the alpine ash zone is in cloud for much of the winter. In its altitudinal range in Victoria snow lies on the ground for from 1-6 months. Because of permanent snow and the typically wet late autumn, winter to spring period in Victoria, utilisation practices are usually restricted to the period October or November through to May.

Alpine ash does not form lignotubers or coppice from felling stumps, and is fairly fire-sensitive in spite of the 2-3 inches thickness of fibrous bark on the lower part of the trunk of mature trees. On better quality sites it grows to heights of 250 feet and over, with diameters to 10 feet, and merchantable log lengths to 140 feet, (Ferguson 1957). In virgin stands of approximate age 110 years in Victoria merchantable volume of 100,000 super feet per acre (Hoppus measure) occur, but the average is only about 35,000 super feet.

In Victoria it grows best on soils derived from granitic and basaltic type rocks, and metamorphosed formations; but also grows well on soils derived from Ordovician, Permo-carboniferous, Silurian and Dewonian sediments. The soils may usually be classified as alpine humus soils or mountain podsols (brown forest soils). In Tasmania the species is more common on normal podsols developed from dolerites (Rodger 1953).

Silvical characteristics and the silviculture of the species have been studied during recent years in representative stands in the highlands of north-eastern Victoria. Early data from this study have been published (Grose 1957 and 1960a.) Some of this evidence and some from later work (Grose 1960 b) is reviewed below.

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SILVICAL CHARACTERISTICS

Germination and Dormancy of Seeds.

Most alpine ash seeds are dormant and consequently germinate poorly at constant temperatures of 10°C and higher (Table 1). Some lower temperatures favour after-ripening, and at these temperatures high capacity germination is achieved but germination is very slow.

TABLE 1

Mean Germination and Germinative Energy for 7 lots of untreated *E. delegatensis* seeds germinated at various constant temperatures

Temperature °C	Mean Germination per cent	Mean Energy Index (*)
2	0	0
5	94.8	.231
7	96.7	.281
10	3.3	.277
13	14.0	.342
17	25.7	.546
21	7.6	.579
24	0	0

(*) Index proposed by Bartlett (1938).

Trials in which seeds were incubated in a comprehensive series of alternating-temperature programmes showed that alternating temperatures are less favourable for germination of untreated seeds than 17°C the approximate optimal constant temperature. Seeds of 87 lots collected over a wide geographic range of altitude and aspects had a mean germination capacity of 20.9 $\mp$ 13.9 (S.D.) per cent at 17°C. As indicated by the range in their germination capacity, namely 0 — 67.2 per cent, there was quite a range in degree of dormancy between the 87 lots tested; but there was no relationship apparent between degree of dormancy and locality, elevation or aspect of the site of collection.

High percentage and relatively fast germination is achieved at 17°C when seeds are incubated in atmospheres enriched in oxygen, and Dexter (1959) observed a similar response when the seeds were incubated on a germination substrate saturated with a 2 per cent solution of hydrogen peroxide. High capacity germination is also promoted by excising the embryos or incising the inner and outer integuments of the seed coat. This evidence suggests that dormancy of alpine ash seeds is due to poor permeability of the seed coat for gaseous exchange limiting the supply of oxygen to the embryo. This postulate has some support in that an inner membranous skin is common to *E. delegatensis* seeds and to seeds of other plants of which dormancy is attributed to poor permeability of the seed coat, for example, *Pinus spp.* (Stone 1958), *Xanthium* (Davis 1930), and *Cucurbita* (Brown 1940). In addition the germination behaviours of seeds of all of these plants are basically similar and distinctive.

Dormancy of alpine ash seeds is also broken by stratification. Moist storage at 5°C is most effective but only little better than treatment at 7°C. Seeds after-ripen very slowly at 1°C, a temperature close to that experienced under snow by seeds on the field seed bed, while storage at 10°C is even less effective. The effect of stratification at 5°C for various periods on breaking the dormancy of alpine ash seeds is shown by the data in Table 2.

TABLE 2

Mean Germination and Germinative Energy of 6 lots of *E. delegatensis* Seeds stratified at 5°C for 0, 2, 4, 6 and 8 weeks and then incubated at various constant temperatures

Stratification weeks	0	2	4	6	8
Germination Temp. °C.	**Germination per cent**				
5	96.3	96.3	96.3	96.3	96.3
10	3.7	9.2	68.2	94.1	97.6
17	29.3	65.8	93.6	97.8	98.7
21	17.0	58.7	92.1	94.2	98.2
27	0	0	40.9	69.3	85.6
32	0	0	0	17.4	69.2
35	0	0	0	0	17.8
	Germination Energy Index				
5	.245	.290	.321	.375	.474
10	.275	.281	.413	.416	.613
17	.387	.562	.617	.761	.805
21	.549	.683	.803	.846	.915
27	—	—	.794	.856	.955
32	—	—	—	.933	.961
35	—	—	—	—	.981

The data in Table 2 show that 8 weeks' stratification at 5°C is adequate to promote relatively fast and high capacity germination at the near-optimal temperatures of 17° and 21°C, and promotes some germination at 27°C. Stratification for periods longer than 4 weeks increases the rate of germination, extends the range of temperatures at which high capacity germination is achieved, and extends the range of temperatures within which the seeds will germinate. It can be readily seen therefore, that the degree of after-ripening determines the extent to which temperature controls germination capacity and energy.

It should be noted in Table 2 that a germination capacity at 5°C of 96.3 per cent is shown for each stratification period. As 5°C was used both for stratification and incubation in these tests, and as no seeds germinated until after 9 weeks, only one set of samples was retained for the long period required to obtain data for final germination capacity at this low temperature. The germination energy indices were all calculated for this set of samples, the germination period over which they were calculated varying according to the period of stratification.

Primary dormancy of untreated seeds may be strengthened when they are stored at certain temperatures. Whether this strengthening occurs, and the rate at which it proceeds depend on seed moisture content and storage temperature. It follows that the final strength of dormancy depends on these two factors and the period for which the seeds are stored. Rate of strengthening increases with temperature and moisture content, and, because of the interaction between temperature, moisture content, and time, it is difficult to define minimum levels of all or any one of these factors which conduce to strengthening of dormancy. There is no appreciable increase in primary dormancy in seeds stored at 5° — 20°C with a moisture content of 5 m 10 per cent, oven dry weight basis.

The primary dormancy of seeds shed naturally from trees on to the field seed bed in summer is strengthened in late summer and early autumn. This feature of strengthened primary dormancy gives seeds shed on to the field seed-bed even less chance of germinating before winter.

Secondary dormancy is induced in after-ripened seeds when they are stored at temperatures and/or moisture contents unfavourable for germination. As with strengthened primary dormancy, the rate at which secondary dormancy is induced, increase with moisture content and temperature within the ranges of these that limit germination. As degree of after-ripening determines the range of temperatures within which seeds can germinate, it also determines the minimum temperature that will induce secondary dormancy in some or all seeds when moisture is favourable for germination. When moisture is limiting, secondary dormancy is induced by storage at temperatures of 5°C and above. Seeds that have overwintered, and are at or near the surface of the field seed bed in spring, commonly experience wide and rapid fluctuations in temperature and moisture content and assume a secondary dormancy. Embryos of fully after-ripened seeds are damaged when the seeds dry to a moisture content of approximately 15 per cent or lower after stratification.

These features of primary dormancy and secondary dormancy have a marked influence on germination behaviour of seeds in the field.

Flowering and Seed Production

Inflorescence buds appear in leaf axils during November to December, and 12 months later the bracts of these buds are shed to start the flower-bud stage. These buds develop for a further 14-16 months before flowering, so that flowering occurs in January-March a little more than two years after the appearance of the inflorescence buds. Seeds are mature 20-24 months after flowering and if harvested in this condition retain their viability for 10 years in favourable storage.

Natural shedding of a seed crop does not normally start until almost 2 years after flowering. Because of the infrequency of seed years, the usual time taken for most seeds of a crop to be shed is not known. A seed crop may be shed in the third and fourth vears after flowering, or may contribute the main seed-fall over a period of four years, with similar proportions of the crop being shed each year.

The main period of cast of seeds from capsules, namely free seeds, is February-April, but some free seeds are shed in most months. Cast of seed in capsules is restricted mainly to autumn and winter, being mainly due to wind and snow breaking off mature fruiting branchlets, umbels and single capsules. In the period 1955-60, the average annual cast of seed from full canopy of alpine ash stands aged approximately 105-110 years was 1.25 million seeds per acre, of which 57 per cent was shed as free seeds and the remainder as seeds in capsules.

A significant factor in the silviculture of alpine ash is that stands on northerly and westerly aspects may produce almost twice the amount of seed set by similar stands on southerly and easterly slopes. Stands aged 55-60 years set only about 1/6 th the amount set by stands aged 105-110 years.

Fate of Seeds on the Ground

Evidence indicates that most seeds shed in capsules are eaten by insects or become non-viable within the capsules, and thus contribute little seed for purposes of regeneration. Insects also harvest 50-75 per cent of free seeds. A small percentage of free seeds germinates in autumn, but the resultant germinates die before spring. Some other free seeds become non-viable before spring, hence, from the evidence available, it appears that the approximate mean percentage of free seeds that is available for germination in spring will usually be from only 15-34 per cent of the total fall.

Free seeds after-ripen on the field seed-bed in winter and will germinate readily in spring if moisture and temperature conditions are favourable. Seeds protected from wide fluctuations in temperature and moisture content by a mulch or shade usually germinate in spring soon after snow-thaw. Unless the spring is abnormally wet and cool, exposed seeds usually become dormant again. Free seeds which over winter and fail to germinate in spring, become non-viable before conditions favourable for their germination recur. Consequently no store of seed accumulates on the field seed-bed. It can be seen then that seed for germination in the first spring after logging may come from the stands just before and during logging, and from the retained seed source. Seed for germination in subsequent springs must come from the retained seed-source.

Ash beds provided by broadcast slash fires and loosely cultivated seed beds, on each of which many seeds may become covered with a protective layer by the actions of rain-splash, surface run-off and frost, are most favourable for germination. Compacted bare soil is relatively unfavourable, and grass — and litter — covered seed beds are even less favourable for germination. Percentage germination of seeds on receptive seed-bed on sites protected by aspect or shade is often at least twice that of seeds on similar seed bed on exposed sites. This difference in germination between aspects may usually overcome the problems imposed by differential seed production between exposed and sheltered aspects.

Seedling deaths

Losses of seedlings in the cotyledon and two-leaf stages are high on all seed beds. On bare soil and ash bed, the two main forms of receptive seed bed, usually 50-60 per cent of the observed germination dies before winter. Most of these deaths are caused through exposure of roots by water-wash and frost-heave, decapitation by ice action, and by lethal high temperatures at the boundary layer between soil and air. Although some seeds germinate in grass particularly when spring is wet, most are killed by spring frosts. Any that survive are usually killed by soil drought in summer.

There are 150-200 frosts annually in the alpine ash zone, and frosts may occur each month of the year. The critical temperature for natural seedlings growing in the open on bare soil, and hardened under field conditions appears to be about 6°-8°F. Temperatures as low as this occur infrequently over bare soil, but are common over grass and freshly-fallen snow. Foliar damage through frosting of seedlings on bare soil or ash bed is usually slight, except in the special circumstances where leaves are wet when frozen, or where freezing temperatures occur under a shallow layer of snow. When snow is absent, the only action of frosts which has any significance in establishment of natural regeneration on bare seed beds appears to be frost-heave. Approximately 25 per cent of seedlings on these seed beds are killed by frost-heave in spring when in the cotyledon stage. In autumn frost-heave may also kill 30-60 per cent of seedlings aged 6 months growing on snig tracks on sheltered wet sites, but few seedlings growing on exposed and drier sites are killed by frost-heave when of this age.

Worthwhile numbers of seedlings develop and survive until winter on two types of seed bed, namely, bare soil and ash bed. Of these, seedlings on ash bed survive winter snow much better than those on bare soil. This is evidenced below where the winter mortality of healthy seedlings of approximate age 6 months on bare soil just prior to snow-fall is compared with that of similar aged seedlings on ash bed (Table 3).

TABLE 3

Winter mortality of Seedlings growing on seed-beds of bare soil and as bed in their first year.

Year of Winter	Mortality per cent		Period of permanent snow
	Bare Soil	Asth bed	(months)
1955	52	9	3.5
1956	96	49	5.8
1957	46	7	2.3
1958	40	2	2.0
1959	16	0	1.3
1960	84	31	4.6

Death of seedling while covered with snow in their first year appears due primarily to prolonged saturation of the intercellular spaces of the leaves with water from meted snow. The probability of leaves of a seedling becoming injected with water depends on the following factors :

(a) *Glaucousness of the leaves* — Leaves with a waxy cuticle shed water readily and a film of water cannot form over their surface. Leaves of seedlings growing on recent ash bed are more glaucous than those of similar-aged seedlings growing on bare soil. This is one of the factors which leads to the marked difference in winter mortality between seedlings growing on the two types of seed bed. Leaves of seedlings growing on *bare soil* on exposed sites are much more glaucous than those of seedlings on shaded moist sites, whereas there is little difference in leaf glaucousness between seedlings growing on *ash bed* on exposed and shaded moist sites. The effect of shelter provided by aspect or on edge of trees, etc., on leaf glaucousness of seedlings growing on *bare-soil* seed beds, and the attendant increase in susceptibility of the seedlings to «winter-kill», are very significant factors in determining regenerative techniques.

Although similar numbers of seedlings may reach age 6 months on bare soil on contrasting aspects, the number of seedlings on *bare soil* on exposed sites that survive the winter is usually about five times greater than the number that survive the winter on bare soil on shaded sites. Shelter has little effect on winter mortality of seedlings on ash bed.

(b) *Size of Seedlings.* Small seedlings are often flattened by snow, and during winter they are held in the very wet zone at the soil-snow junction. In this position, injection of their leaves with water would usually be rapid. Many seedlings of approximate age 6 months growing on bare soil are flattened in this way. This is considered to be a further reason for the difference in winter mortality petween these seedlings and the more robust seedlings of similar age growing on ash bed. The different rates of growth of seedlings on the two types of seed bed are evidenced by the following data for seedlings aged 6 months.

	Bare Soil	*Ash bed*
Mean (range). height (inches)	4.2 (1.5-10.0)	12.6 (6-30)
Mean (range) No. of leaves	7 (4-10)	14 (9-38)

(c) *Habit of Leaves* — Whether the leaves hang vertically or are held horizontally, determines to some extent the chances of leaves becoming injected with water. The first 3-4 pairs of leaves produced by young alpine ash seedlings are dorsiventral. These are held more or less horizontally and, when under snow, tend to retain a small pool of water on their upper surface. Leaves produced later are isobilateral or nearly so. These hang vertically and shed water from melted snow readily. In addition, on a given seedling, isobilateral leaves are more glaucous than dorsiventral leaves. Because of the different initial growth rate of seedlings on bare soil and those on recent ash bed, most leaves produced by seedlings on bare soil in their first year are dorsiventral, whereas most leaves produced in the same time by seedlings on ash bed are isobilateral. This factor is also considered to be one of the determinants of the higher death rate in winter of young seedlings on bare soil compared with that of those on ash bed.

(d) *Period of Snow Cover* — Winter mortality increases with period of snow cover (Table 3). This may be partly due to longer periods in wet conditions increasing the chance of leaves becoming injected with water. In addition, as the period under snow would determine the time for which leaves remain injected, the chances of injection proving lethal would be increased. Laboratory trials have shown that injected leaves have to be held for approximately 3 weeks at 33°F, the usual temperature under snow, to cause irreversible changes that lead to death of the leaf tissue.

The feature of winter mortality is stressed because it is so significant in determining the success of regeneration. The above evidence shows that, in some years, almost all 6-months-old seedlings on bare soil die while covered with snow, irrespective of their exposure during early growth. In addition, shading during growth makes seedlings on bare soil very susceptible to damage in winter. The resistance to winter damage shown by seedlings on recent ash bed contrasts markedly with that of seedlings on bare soil, and clearly, provision of an ash bed would provide best chance of success in regenerating the species following utilisation.

Seedling Per cent

Percentage germination observed at the cotyledon stage on loose bare soil and recent ash bed may usually approximate 20 per cent. However, when only 15-34 per cent of all free seeds shed are present and viable in spring, percentage germination to the cotyledon stage of this total seed would be only 3-7 per cent. When seedling deaths as described above are taken into account, the approximate average values for established-seedling per cent of total free seed resolve as 0.6-1.8 per cent for loose bare soil, and 1.1-3.1 per cent for recent ash bed.

It is clear then, that for a given quantity of seed per acre, the greatest number of established seedlings will be obtained if most of the seed bed is ash bed. Fewer seedlings will be obtained as quality, area and distribution of receptive seed bed decreases from this desirable condition.

SILVICULTURAL TECHNIQUES

As alpine ash seedlings establish only on a *bare seed-bea,* success in natural regeneration depends largely on the area and distribution of seed-bed bared during logging or by subsequent cultivation or prescribed burning. Although the established-seedling per cent is higher on *ash-bed* than on *bare soil,* soil bared during logging or by subsequent cultivation is a suitable seed-bed for regenerating unshaded aspects. It should be both practicable and economic to prepare sufficient area and suitable distribution of *bare soil* for regeneration on these aspects when slopes are less than approximately 20 degrees. On unshaded sites with steeper slopes, it may usually be necessry for practical reasons to burn slash to provide sufficient receptive seed-bed. Because of the low established-seedling per cent on *bare soil* on shaded aspects, sufficient seed could rarely be provided naturally to fully regenerate these sites when *bare soil* is the only form of receptive seed-bed provided. There is a much better chance of naturally regenerating these sites satisfactorily if an *ash-bed* is provided by burning slash soon after logging.

Because of the influence of shading on the susceptibility of seedlings to «winter-kill», any shelter-wood system of cutting is not appropriate for use with this species, on either shaded or unshaded aspects, at elevations where snow lies on the ground for longer than 2-3 weeks in winter. Most alpine ash forests occur in this elevational zone, and it appears therefore that a scattered seed-tree system of cutting is the most suitable for use with this species. However, at lower elevations where heavy winter mortality of seedlings shaded during their first year of growth is unlikely to occur, a shelter-wood type of cutting may prove successful.

The seed crop carried by stands aged 100-110 years should always be adequate for the purposes of regeneration. However, as pointed out above, seed must be shed on to receptive seedbed to effect regeneration. In the seed-tree system of cutting, most of the seed on the heads of felled trees falls on non-receptive seed-bed. It is important therefore that techniques be used whereby much of the seed on trees to be felled is disseminated on receptive seed-bed before they are felled. This may be achieved by a «two-cut» system in which some or all of the trees left for the second cut are sap-ringed to induce rapid seed-fall. Obviously, the value of this technique depends greatly on the area and dispersion of receptive seed-bed prepared before the sap-ringed trees shed their seed.

On all sites where additional receptive seed-bed may have to be prepared by prescribed burning or cultivation after logging the second cut, 3-4 selected trees per acre should be retained to regenerate the additionally prepared seed-béd. Studies of seed dissemination and of quantities of seed shed per tree per year show that this number of trees would usually provide adequate seed. Even where sufficient seed-bed was provided before seed was shed from sap-ringed trees, it would be advisable to retain a similar seed source for insurance in case of failure in the first year or early destruction of the regeneration by fire.

ACKNOWLEDGEMENTS

Some of the information reported above was gathered in a project of the Research Branch, Forests Commission, Victoria, and some during my tenure of the A.P.M. Research Fellowship in Forestry at the University of Melbourne. The helpful guidance given in the work by Mr. W. J. Zimmer, Chief Forest Research Officer, Forests Commission, Victoria, and Mr. J. H. Chinner, Reader-in-Charge of Forestry, University of Melbourne, is gratefully acknowledged.

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AVAILABILITY OF *E. DELEGATENSIS* SEED

A total quantity of up to 50 pounds of seed could be supplied annually by this Department. As this would usually be collected on demand, it can be collected only during the snow-free period.

A pound of seed usually contains about 45,000 viable seeds.

QUELQUES CARACTÉRISTIQUES SYLVICOLES D'EUCALYPTUS ET RÉFÉRENCES À SA CULTURE

Résumé

L'auteur fait une brève présentation des régions où l'on trouve l'*Eucalyptus delegatensis,* couramment connu en Australie sous le nom de "alpine ash", espèce indigène dans la partie sud-est du pays. Il aborde ensuite le problème de la germination des semences, la production de celles-ci, les pertes pendant la transplantation, et, finalement, les techniques de sa culture. A ce sujet, il dit que le succès de la régénération naturelle de cette espèce dépend largement de la nature du terrain et de la distribution des semences pendant la coupe, etc.

ALGUNAS CARACTERISTICAS SILVICOLAS DE *EUCALYPTUS DELEGATENSIS, Y REFERENCIAS SOBRE SU CULTIVO*

Resumen

El trabajo comienza con una breve presentación de las areas de ocurrencia de *Eucalyptus delegatensis,* comunmente conocido en Australia por "alpine ash", indigena en la parte sudeste del pais. Se refere en seguida el problema de la germinacion de sus semillas, produccion de las mismas, perdidas por transplante y finalmente las tecnicas de cultivo. A este respecto se expresa que el exito de la regeneracion natural de la especie depende, en alta escala, de la naturaleza del terreno y de la dispersión de semillas durante los trabajos de tala del bosque, bien que, del hecho de ser el terreno, subsecuentemente quemado y cultivado.

ALGUNS CARATERÍSTICOS SILVÍCOLAS DO *EUCALYPTUS DELEGATENSIS* E NOTAS SÔBRE A SUA CULTURA

Resumo

O autor começa com uma breve apresentação das áreas de ocorrência do *Eucalyptus delegatensis,* comumente conhecido na Austrália por "alpine ash". Em seguida, fala do problema da germinação das suas sementes, produção destas, perdas de mudas, e por fim, das técnicas de cultura. A êste último respeito, diz que o sucesso da regeneração natural desta espécie depende em larga escala da natureza do terreno e da distribuição das sementes durante os trabalhos de corte da floresta, bem assim, do fato de ser dito terreno, subsequentemente, queimado e cultivado.