Alpine Ash in Victoria's Native Forests

Ecology, Silviculture and Active Management, including Restoration

Silviculture Reference Manual No. 5

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We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it.

We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

DEECA is committed to genuinely partnering with Victorian Traditional Owners and Victoria's Aboriginal community to progress their aspirations.

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Foreword

Honorary Professor Rod Keenan, University of Melbourne

Silviculture uses ecological principles to modify the structure and development of forests to meet specified objectives. These may be to produce income from forest products, improve wildlife habitat, provide quality water, offer recreational opportunities, and many other values. In his classic text, *The Practice of Silviculture*[1], Smith said, "a good silvicultural system is not chosen but formulated as a solution to a specific set of circumstances". This requires knowledge of the regeneration requirements of desired tree species, ensuring seedlings pass through the early stages of development and grow well with competition managed. The silvicultural decision also requires understanding of effects of varying site and climatic conditions, the need to satisfy environmental standards, market needs, and prevailing socio-economic factors and management efficiency[2].

Alpine Ash (*Eucalyptus delegatensis*) forests occupy a particular place in the heart of many Australians. These forests form a broad band on well-drained, deep soils around high-country snow gums and grassy plains in south-eastern Australia, from the ACT's Brindabella Ranges in the north, throughout Victoria's alpine region, to Tasmania's Hartz Mountains in the south. They herald the entrance to another world, where cooler, cleaner air and clearer skies abound, and where we can escape the heat and challenges of the lowlands. These forests also have a particular place in my heart. I began my research career in Tasmania's 'White-top' forests[3] in the early 1980s, spending four absorbing (and often rather cold) years beginning to work out how forests function, and to work out who I was, and what I wanted to do in life.

Indigenous Australians have interacted with these forests for many thousands of years. People and forests have shifted extensively over time with changing climate, but western science knows relatively little about how Indigenous Australians influenced forest structure, composition and distribution. We do know that in the high-country of northern Tasmania, for example, a landscape dominated by Alpine Ash, with a grassy understorey maintained by the activity of indigenous Australians, changed through rapid conversion to rainforest and dieback of eucalypts following removal of Aboriginal people and their interaction with these forests[4].

With excellent timber properties, these forests were cut heavily for sawlogs from the early days of European settlement, and later also for papermaking. The best trees were

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1 Smith, D.M. (1962). The Practice of Silviculture. John Wiley and Sons, New York. 7th edn., 578 pp.
2 Florence, R.G. (1978). The silvicultural decision, Forest Ecology and Management 1, 293-306.
3 One of the common names for Tasmania's Alpine Ash subspecies.
4 Fletcher, M.-S., Hall, T., Alexandra, A.N. (2021). The loss of an indigenous constructed landscape following British invasion of Australia: An insight into the deep human imprint on the Australian landscape, Ambio 50, 138-149.

removed during these early years, often leaving the forest in a degraded condition from a timber production perspective. Forest research pioneers, like Dr Ron Grose in the 1950s and 60s, discovered insights into the seed germination and regeneration needs of Alpine Ash, providing the knowledge and capacity for successful forest regeneration and stand management following more recent harvesting or other disturbances. Many advances in silviculture have since been made.

As an obligate seeder with a narrow climate niche and specific needs for regeneration, Alpine Ash is one of the more vulnerable eucalypt species to a changing climate. This vulnerability is amplified by more frequent, intense wildfires that have swept through south-eastern Australia over the last 20 years. Repeated fires are placing new pressures on Alpine Ash forests, with significant areas being burnt multiple times at intervals too short for regenerating trees to reach an age capable of producing adequate seed for natural regeneration. More intense fires, more heat, drought, frost, competition from other plants, and browsing by native and introduced species present serious challenges for public land managers who are responsible for the maintenance and care of these forests for current and future generations.

Since the authors began preparing this manual, the Victorian Government ceased timber harvesting in native forests on public lands. This manual clearly indicates that active management is required to maintain these forests in a healthy state. As a society, we therefore need to ensure we have the capacity, including resources, to manage and regenerate forests. This includes ongoing monitoring and forecasting of flowering and seed production, and seed collection with careful storage and deployment of sufficient seed under the right conditions. We need to continue to invest in research to improve our understanding of the potential impacts of climate change and to develop options for adapting to cope with these impacts.

I commend the authors for their efforts in bringing together this monumental body of knowledge. Supported by several hundred references, the manual combines the current scientific understanding of the ecology of this iconic eucalypt species with practical, empirical knowledge from observation, monitoring and experience to provide an invaluable resource for forest managers. Even though timber is not currently harvested from Victoria’s native forests on public lands, this knowledge, accumulated through years of observation and experimentation, will support the future management decisions required for these forests.

New circumstances present new challenges. By integrating the knowledge and wisdom of Traditional Owners with these strong scientific foundations built over the past 70 years, we can create a ‘new silviculture’ to manage and care for our precious Alpine Ash forests and ensure they persist to provide benefits for future generations.

Professor Rod Keenan is former Chair of Forest and Ecosystem Sciences at the University of Melbourne. He began his career in forest research in Tasmania and has worked across Australia, in Canada, Papua New Guinea and Southeast Asia. He was a member of the UN-FAO Advisory Group for the Global Forest Resource Assessment from 2003 to 2015

Dedication

This manual is dedicated to Ron Grose, who not only carried out early and comprehensive research on Alpine Ash silvics and silviculture, but also strongly supported research into aspects of forest ecology and recreation.

Ronald Jeffrey Grose, born on 10 December 1929, was the son of a forester, Norm Grose and, as it turned out, the father of a forester, Peter Grose. Ron commenced his forestry training at the Victorian School of Forestry in 1947, graduating in 1949 with the Associate Diploma of Forestry. He later gained a Bachelor of Science in Forestry and a Ph.D. at Melbourne University.

Employed by the Forests Commission of Victoria (FCV), Ron became involved in ground-breaking research through the 1950s, into the genus *Eucalyptus.* Ron often worked with renowned research forester the late Walter Zimmer, and together they published a number of reports on *Eucalyptus* seed characteristics.

Ron's later work focussed on the silvics and silviculture of Alpine Ash (*Eucalyptus delegatensis*), which was then little known in comparison to Mountain *Ash (E. regnans).* Satisfactory regeneration of Alpine Ash following harvesting was problematic due to seed dormancy and other factors influencing germination and growth.

Ron became a Research Fellow in 1959, and then completed his post-graduate studies to gain his Ph.D. His seminal work was published by the University in 1963: "The Silviculture of *Eucalyptus delegatensis*, Part I, Germination and Seed Dormancy". Unfortunately, Part 2 never reached completion, but is covered by his Ph.D. report.

Ron was a first-class research scientist with an abiding interest in the field of practical and successful regeneration and management of Victoria's eucalypt forests.

Ron later worked his way through the ranks of the FCV to Chief, Division of Education and Research, then Chief, Division of Forest Management. In 1977 he was appointed as a Commissioner of Forests and in 1983 he was appointed as Chairman.

In a broader context, and throughout the 1970s, Ron served the wider forestry profession with distinction in his role as President of the Institute of Foresters of Australia and was elected a Fellow of the Institute (now Forestry Australia) in 1975. He also held leadership positions outside the FCV including the Committee of Management of the Mount Buller Alpine Resort, President and Board Chairman of the Natural Resources Conservation League of Victoria.

As his career developed, Ron Grose was held in increasingly high esteem by those in field positions, within related academic circles, in the higher echelons of the Victorian bureaucracy and within both the national and international ‘forest’ communities.

After his departure from the Department of Conservation, Forest and Lands in 1985, Ron continued his lifetime commitment to public service by undertaking a number of assignments for Government.

Sadly, Ron died of a stroke, too early, on 29 May 2007 aged 76. He will be remembered by his colleagues as one of the most capable, dedicated, respected and revered foresters in the history of forest management in Victoria.

Selected images related to Ron’s early work in the 1960s

(Images: Forests Commission Victoria)

Ron pioneered the development of improved seed management for Alpine Ash in the early 1960s, including seed collection (note the machete!) and the aerial sowing of (then) coated seed. Fixed-wing was the aircraft choice of the day, but helicopters with external hoppers were trialled and known to be more accurate. However, high cost thwarted their routine use for many years.

The Authors

Owen Bassett *B.For.Sci. (Melb.), MFA*

Owen is the founding Director of Forest Solutions Pty Ltd, a private consultancy providing silviculture advice to organisations managing native eucalypt forests. Since 2008, the consultancy has delivered a number of government projects, including reviews of forestry in western Victoria and seed management for Victoria's Ash forests. Owen has had a leading role in the recovery of young Ash forests following numerous large bushfires from 2003 to 2020.

He has also produced many technical documents for the State government, including the Silviculture Reference Manual for Box-Ironbark forests and several in the Native Forest Silviculture Guideline series. His varied clients include DEECA, former VicForests, Parks Victoria, HVP Plantations, Trust for Nature, Ion Group, and the Victorian Apiarists Association.

Owen has specialised in native forest silviculture since graduating in 1987. He began his career in applied forest research, studying the seed development and supply of commercial eucalypt species during Victoria's Silvicultural Systems Project. In the early 1990s he began what is today the world's longest, annual floral monitoring study for a forest-tree species, including both of Victoria's Ash species (30 years continuous). He was a Silviculture Officer for the Victorian Government from 1997 to 2007 and has authored over 40 technical reports, guidelines and manuals.

Tom Fairman *B Sci. (Melb), Masters (Forest Ecosystem Science), PhD (Forest & Fire Ecology), MFA*

Tom is a forest scientist who has been involved with native forests for 15 years. Currently he works in forest fire research at the School of Ecosystem & Forest Sciences at The University of Melbourne. He completed his PhD in forest and fire ecology in 2019, focusing on the impact of short-interval, severe bushfires on the structure and demography of temperate forests.

He has previously undertaken research on the carbon dynamics of native forests and the ecosystem services of urban forests. Outside of research, he has worked as an ecological consultant and contributed to the development of forest policy in State government. His main research interests relate to the role of fire in native forests, with a focus on shifting fire regimes, the consequences of this for forest health, and the options available for forest managers to plan and adapt in such landscapes now and in the future.

Peter Fagg *Dip.For. (Cres.), B.Sc. (For.) (Melb.), FFA*

For most of his 45-year career with Victorian Government forestry agencies, Peter specialised in silviculture. His role encompassed policy development, knowledge transfer and the documentation of operations such as regeneration, reforestation, seed management, thinning, and fire recovery within Victorian native State forests.

During his early career spanning 1971-1989, Peter carried out applied silvicultural research, largely with the Forests Commission of Victoria.

During that time in East Gippsland, he investigated the impacts of the Cinnamon Fungus and the regeneration of mixed species forests.

Later, state-wide projects included weed control research in plantations, the Young Eucalypt Program in association with CSIRO, and the Silvicultural Systems Project. Peter has authored or co-authored over 50 publications and, having retired from the Department of Sustainability and Environment in late 2010, is currently a part-time forestry consultant engaged by Forest Solutions Pty Ltd.

Gary Featherston *Dip. For. (Cres), B. Sc. (For.) (Melb.), FFA*

Gary has 43 years' experience with the forest and timber industries from both public land and natural resource management perspectives. He is a qualified and registered professional forester with extensive experience as a senior public sector manager. He has successfully maintained his own consulting service company, Forest Strategy Pty Ltd since 2004. He is an active member of Forestry Australia and was on the National Board.

Following some years in silvicultural research in Gippsland, Gary has extensive experience in the management of forests for multiple objectives, including the safe and environmentally responsible harvesting of native forests and plantations.

Gary has recent experience with forestry compliance activities. He has undertaken Code of Practice audits on contract to local government, managed the review of the Australian Standard for Sustainable Forest Management, and is a provider of technical expert services to the Joint Accreditation System of Australia and New Zealand, an organisation who provide accreditation services to forest management auditors.

Purpose and Content of this Manual

This manual is designed as a reference for all people who contribute to the management of native Alpine Ash forests in Victoria. Note that it has been finalised at a time when the State government announced an end to timber harvesting in Victoria's State forests. However, the manual still refers to timber harvesting techniques as a record of knowledge, and to reflect on how operations were undertaken when the timber industry existed. In fact, much of the knowledge about Alpine Ash has been developed by foresters from that industry, and this manual is therefore, in part, a tribute to them. Although timber harvesting has ceased, tending forests using 'active forest management' continues to be essential, and is now considered relevant to all land tenures. Threats posed by sudden changes in climate add their challenge, and the dynamics of forest structure, species mix and fire frequency of many Ash forests are imbalanced and need restoration. As such, today's forest managers will find knowledge in these pages to assist when developing a 'new silviculture' required to restore these forest dynamics. Educators like park rangers and teachers, students and field naturalists, and other forest users like apiarists and Traditional Owners will also find value in this publication, especially the ecological information provided in **Chapters 1-4**.

Definitions of technical terms are given in the **Glossary** at the back of this manual. An **Index** to assist readers is also provided. **Chapters 1 & 2** introduce and celebrate Alpine Ash, then present a history of land use. **Chapters 3 & 4** document fundamental silvical and ecological information about Alpine Ash including distribution, growth, associated flora and fauna, influences of fire, pests and diseases, seed production, and seedling establishment and survival. **Chapter 5** describes historical silvicultural practices and techniques that were used for timber production in Victoria. **Chapters 6 & 7** deal with active management and forest restoration, including the recovery of Ash forests following bushfire, and reforestation where Ash forests have been absent for years.

This manual is not intended to be a prescriptive operational document. Other documents like Native Forest Silviculture Guidelines (Victoria's 'NFSG series') and State Plans and organisational procedures fill this role. Rather, it brings together a large parcel of information and knowledge about Alpine Ash in one document, to inform the reader.

Other Silviculture Reference Manuals in this series

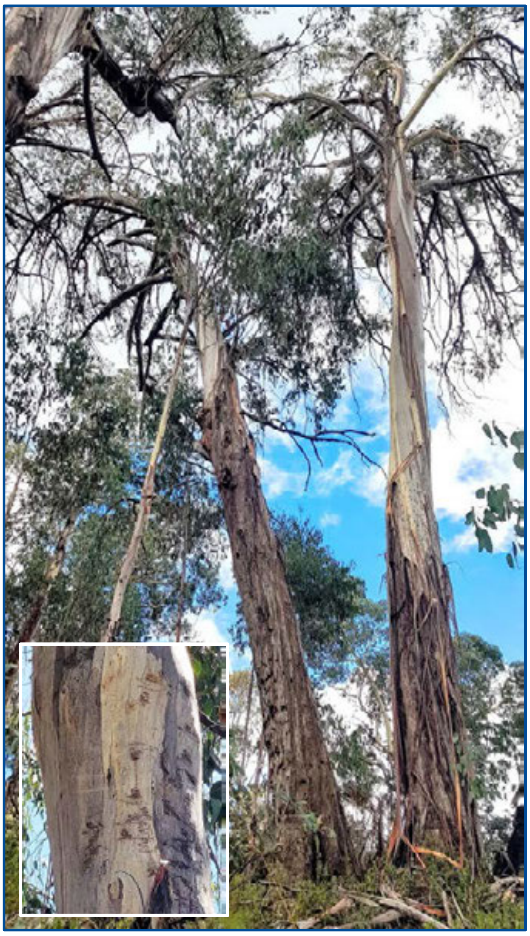
No.	Forest type	Authors	Reference
1	Mountain Ash	Andrew Flint & Peter Fagg	Flint & Fagg (2007)
2	High elevation mixed species	Ian Sebire & Peter Fagg	Sebire & Fagg (2009)
3	Low elevation mixed species	Simon Murphy, Ron Hateley & Peter Fagg	Murphy *et al.* (2013)
4	Box-Ironbark	Peter Fagg & Owen Bassett	Fagg & Bassett (2015)

Digital copies available at https://www.victoriasforestryheritage.org.au/forest-estate/native-forests/silviculture.html

Table of Contents

1. Introduction

Alpine Ash (*Eucalyptus delegatensis ssp. delegatensis* R.T. Baker) is one of Australia's iconic eucalypt species, forming dense forest stands in the wetter, sub-alpine region of the Great Dividing Range. The species grows tall, often producing the famous cathedral-like forest structure that is appreciated by those who walk beneath its canopy (**Figures 1 & 2**). In grandeur, Alpine Ash is only surpassed by the even-taller Mountain Ash (*E. regnans*), found at lower elevations and often as a neighbouring forest-type on mountain slopes just below.



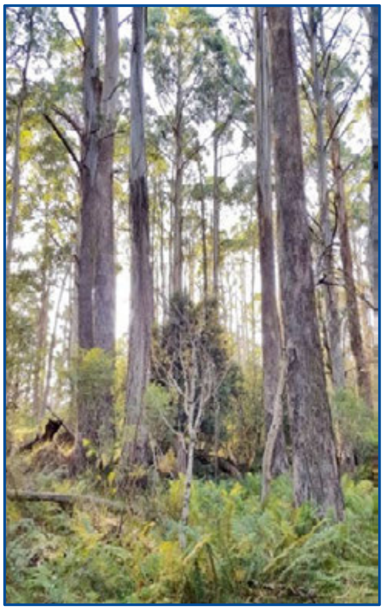


Figure 1. (Left) Alpine Ash in the Mount Buffalo National Park, showing the distinctive tall, straight stems complete with the classic squiggles caused by insect larvae **(inset)**, typical of the species.

(Above) The golden light of morning filters through mature Alpine Ash forest in the Upper Yarra water catchment.

Forests dominated by Alpine Ash form a complex, and dynamic native ecosystem. They are home to a diversity of flora and fauna, some endemic to alpine environments, while others represent a wide-range of life-forms; from terrestrial orchids to understorey trees and shrubs, from insects to arboreal gliders, and from the tiny Robins and Wrens to larger birds like the Superb Lyrebird. Alpine Ash is therefore a much celebrated forest type, worthy of our enjoyment, attentive study and careful management.

In Victoria, Alpine Ash is distributed throughout the sub-alpine areas of central, north-eastern and eastern Victoria and is also commonly known as ‘Woollybutt’. Extensive areas of Ash are currently reserved in State forests for uses such as protecting biodiversity values, recreation, and low impact commercial operations like apiary services. As of 2024, commercial production of timber is no longer included. Ash also occurs in reserves such as National Parks and water catchments, from which water is supplied for multiple uses (**Figure 2**). **Section 1.2** provides details of Ash distribution and its forested area by tenure.

Figure 2. (Above) Airborne: Alpine Ash in the Thomson River Forest Reserve (water catchment) on the eastern slopes of Mt Baw Baw in 2022, showing multiple use for; (1) water storage, (2) past timber harvesting and regeneration, and (3) biodiversity conservation in zones excluded from harvesting.

(Right) Mr. Geoff Cook, resident of Bright in NE Victoria, enjoying a bushwalk under Alpine Ash in April 2022 on his way to Reed’s Lookout, Mt. Buffalo National Park.

Alpine Ash (ssp. *delegatensis*) also occurs in South-east New South Wales and the Australian Capital Territory, where it is also known as ‘Woollybutt’. In Tasmania, where the endemic subspecies *tasmaniensis* occurs, it is known as ‘White Top’ or ‘Blue Leaf’.

These distinctive forests can provide many benefits, including:

- Conservation of flora and fauna
- Protection of water catchments and supply of clean water
- Sequestration and storage of carbon
- Forest products like wood, and nectar and pollen for honey bees
- Provision of recreational and educational opportunities, and
- Protection of landscape, archaeological and historic values.

1.1 Distribution and area of Alpine Ash forest in Victoria

In Victoria, Alpine Ash covers a wide range of sub-alpine sites along the Great Dividing Range and in East Gippsland (**Figures 3 & 4**). Major areas of Alpine Ash include Mt Stirling, Mt Wills, Moroka River, Mt Skene, Mt Whitelaw, the Tea-tree Range, and the areas mentioned below. There is a small, western outlier at Mt Macedon, north-west of Melbourne.

Area of Alpine Ash forest by land tenure is shown in **Table 1**.

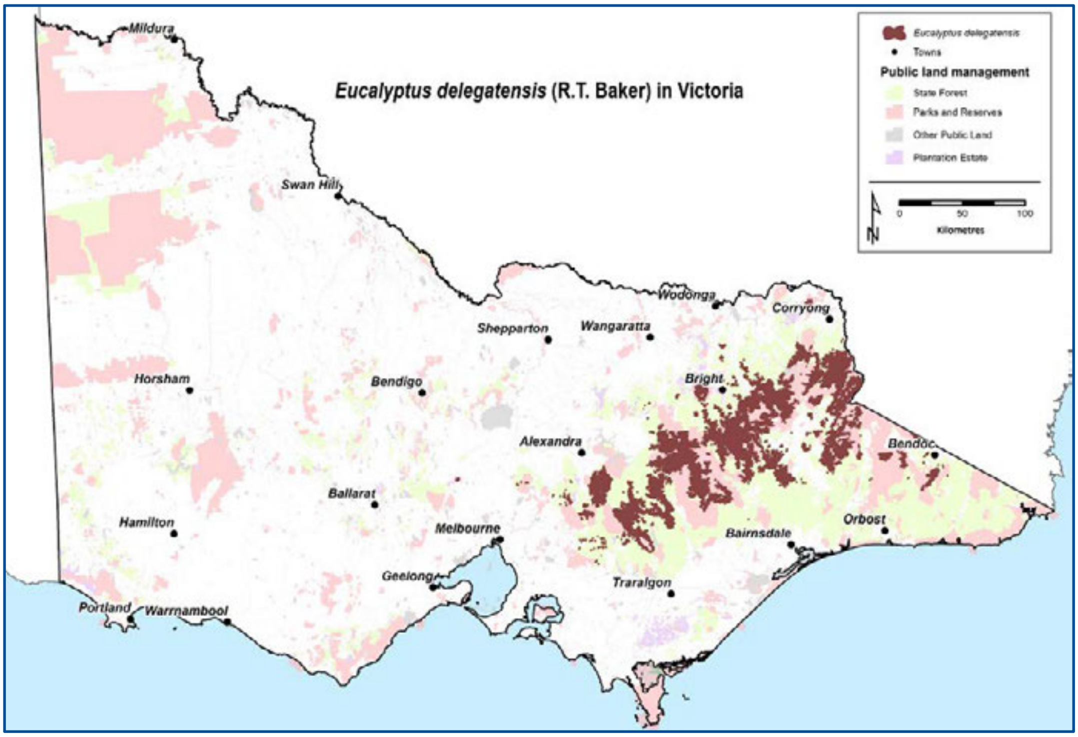


Figure 3. Distribution of Alpine Ash along the Great Dividing Range in eastern Victoria (map: Mick Hansby)[5].

The full altitudinal range of Alpine Ash in Victoria is from about 900 to 1,500 metres. At elevations below about 900 metres within the Central Highlands, Mountain Ash (*Eucalyptus regnans*) will normally occur, with this association present but less common into East Gippsland. In a few places like Mt Stirling, NE Victoria, and Nunniong Plateau, East Gippsland, high elevation Messmate (*Eucalyptus obliqua*) is found neighbouring Alpine Ash at its lowest elevation.

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[5] *Alpine Ash distribution (***Figure 3***)*

The distribution is based on a combination of the Statewide Forest Resource Inventory (SFRI), utilising all three levels of predominance ('pure', 'predominant' and 'mixture') and the S_Veg100 dataset, utilising the two main species identifiers, 'X_spp1' and 'X_spp2'. This combination accounts for the species' extent across public lands (State forest and Parks Victoria estates) and private land as at 2022 (State government data, Victoria).

Table 1. Area of Alpine Ash forest in Victoria by tenure, as at March 2022 (hectares).[6]

Tenure		Alpine Ash (ha)	Other native forest (ha)	Total native forest (ha)	*Proportion of tenure that is Alpine Ash (%)*
Crown Land	**State forest**	**224,750**	2,972,580	3,197,330	*7.0%*
	Parks & Reserves	**154,270**	4,009,470	4,163,740	*3.7%*
	Other Public Land	**120**	514,680	514,800	*<0.1%*
Private		**1,010**	13,090	14,100	*7.2%*
Total native forest (ha)		**380,150**	7,509,820	7,889,970	*4.8%*

Alpine Ash generally grows in pure stands but may be associated at elevations of approximately 900-1,000 metres with Narrow-leaved Peppermint (*E. robertsonii),* Mountain Gum *(E. dalrympleana)* or Messmate (*E. obliqua*). At its upper elevational limit, Alpine Ash can be found mixed with Snow Gum (*E. pauciflora ssp pauciflora*), which will eventually take over as pure stands above 1,500 metres (Boland *et al.* 2006).

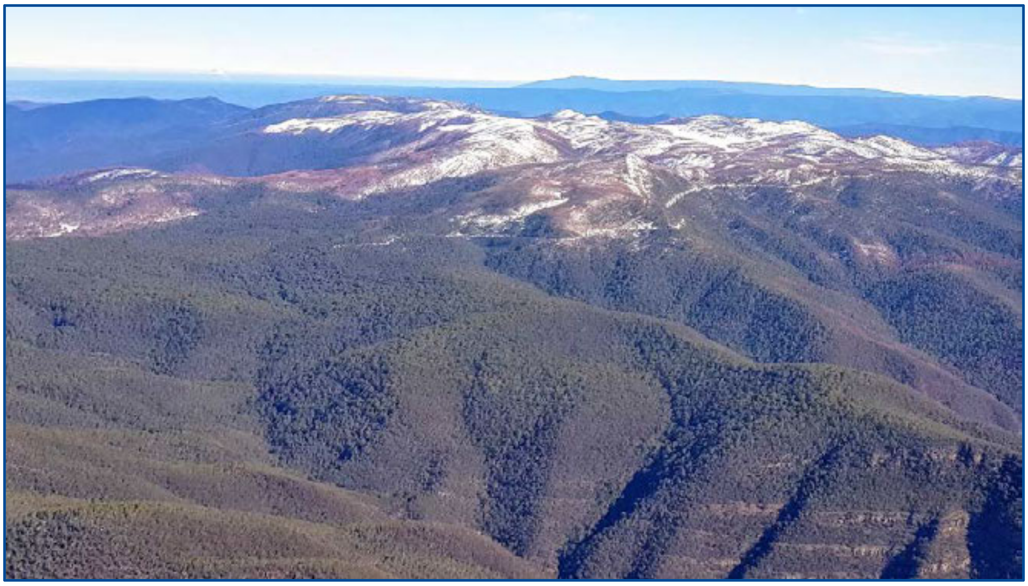

Figure 4. Airborne: Part of Victoria's magnificent Alpine Region looking from above the Avon Wilderness area in Gippsland, northwards to Hotham Heights. Alpine Ash forest is conspicuous on ridges and southern slopes in the foreground by its red-brown canopy.

[6] *Area Analysis (***Table 1***)*
Area by land tenure was derived by an 'intersect' geoprocessing operation. The cleaned Alpine Ash distribution dataset (**Figure 3**) was intersected against the Public Land Management (PLM25) dataset, resulting in a dataset used to create this 'area by tenure' statement. No manipulation of the PLM25 dataset was undertaken, so the accuracy of this analysis is constrained by the accuracy of the dataset. Data is rounded to the nearest 10 ha.

Some multi-aged stands occur naturally in ecotones and forest areas experiencing a mosaic of lower severity fires - after which epicormic growth on Alpine Ash can occur. However, this is rare, given moderate to high severity bushfire nearly always kills Alpine Ash (see **Sections 3.1.2 & 3.2**).

The understorey vegetation is normally of moderate to low density, either dominated by an open grassy herb-rich layer, or consisting of understorey trees with genera such as *Acacia*. In places like Mt St Gwinear, rainforest species such as *Nothofagus* persist (see **Section 3.1**).

Throughout its distribution, Alpine Ash is often dominant in tall open forests on well-drained, humus-rich brown loamy soils (Ashton 1981), often of sedimentary or granitic origin, rocky slopes and deep valleys. However, it can also be common on some plateaus such as Connors Plains and Nunniong Plateau. **Section 3.1.2** has more detail on forest communities.

In Victoria, as of 2024, the remaining reproductively mature stands of live Alpine Ash are found in the following District locations: Mt Wills to Trappers Gap, and the West Kiewa (Ovens), Mt Stirling (Mansfield), Mt Bullfight to the Blue Range (Alexandra), Matlock and the Upper Yarra catchment (Marysville and Noojee), Mts Skene, Useful and Baw Baw (spanning Mansfield, Heyfield and Erica), Mts Delusion, Baldhead and Phipps, and part of the Nunniong Plateau (Swifts Creek). Such areas largely escaped the bushfires of 2003, 2006/07, 2009, 2013 and 2019/20, which killed many mature forest stands, resulting in extensive young Ash regrowth (**Figure 5**; Fagg *et al.* 2013; Bassett *et al.* 2015; Fairman *et al.* 2016; Bassett *et al.* 2021; Fairman 2022).

Figure 5. Airborne: Immature Alpine Ash regrowth in the Upper Murray, regenerating below fire-killed stags, post 2003 bushfires.

1.2 General features of Alpine Ash trees and stands

Appearance. The bark of a mature Victorian Alpine Ash tree is grey to brown woolly-fibrous and fissured to about half the trunk height[7]. Above that, the bark is smooth, white or bluish-grey, peeling in long strips, commonly showing ‘scribbles’ caused by insect larvae (**inset Figure 1**). A young seedling of the species is recognized by its broad, asymmetrical, blue-green or glaucous leaves (**Figure 6**), which gradually change to a green colour by the time the tree is a sapling (Costermans 2009).

[7] The Tasmanian subspecies – rough bark persists on the stem to the base of branches (Nicolle 2022).

Alpine Ash forests typically form pure, even-aged stands (**Figure 1**). The species is readily killed by bushfires, but then regenerates prolifically from seed induced to fall by heat from the fire (**Figure 6**). Intense fire kills approximately 95% of the mature trees, leaving them standing as stark, white 'skeletons of the forest' (**Figure 6**; see also **Section 2.2.1** for details). Alpine Ash is an 'obligate seeder', meaning it relies exclusively on seed for regeneration. Although trees of *spp. delegatensis* do have epicormic buds, they occur under relatively thin bark and are therefore susceptible to intense bushfires, rarely having the chance to sprout.

Figure 6. (Above) An Alpine Ash seedling after its first year, displaying the blue-green leaf stage typical of juvenile regrowth, with new tip-growth in dark red to orange hues.

(Right) Alpine Ash regrowth emerging from below fire-killed mature Ash near Mt. Hotham in the Alpine National Park. This image was taken almost 3 years after the 2013 Harrietville-Alpine bushfire.

Early natural mortality. A study by Fagg (1981) found that an aerial sowing of Alpine Ash seed, at a high but unknown rate onto a disturbed soil seedbed on Errinundra Plateau, produced a very high seedling density which by 8 years of age had naturally reduced to approximately 15,000 stems/ha (87% mortality) with a mean dominant height of 16 m (**Figure 7**). Faunt (2002) found natural mortality of unthinned Alpine Ash stands established in the 1960s to range from 65-80% over a 32 year period, from age 26 to 58 years.

Volume growth. Young trees are capable of rapid early height growth (2 m/yr) under favourable conditions. Mean Annual Increments (MAI) of 7-10 m^3/ha can be achieved, peaking between ages 80-90 years. After an early thinning (at 7 years of age) to retain 200 stems/ha, a stand near Healesville achieved an MAI of 13 m^3/ha (Borough *et al.* 1976). A yield table showed that an unthinned, natural 60-year old stand of Alpine Ash, at Bago NSW, could have a basal area of 58 m^2/ha, a height of 42 m, and a standing volume of 763 m^3/ha (MAI of 12.7 m^3/ha) (Borough *et al.* 1976). However, following the January 2003 fires in NE Victoria, the log salvage program estimated the yield of mainly 1939-origin Alpine Ash sawlog to be 230 m^3/ha (Theobald and Lawlor 2006).

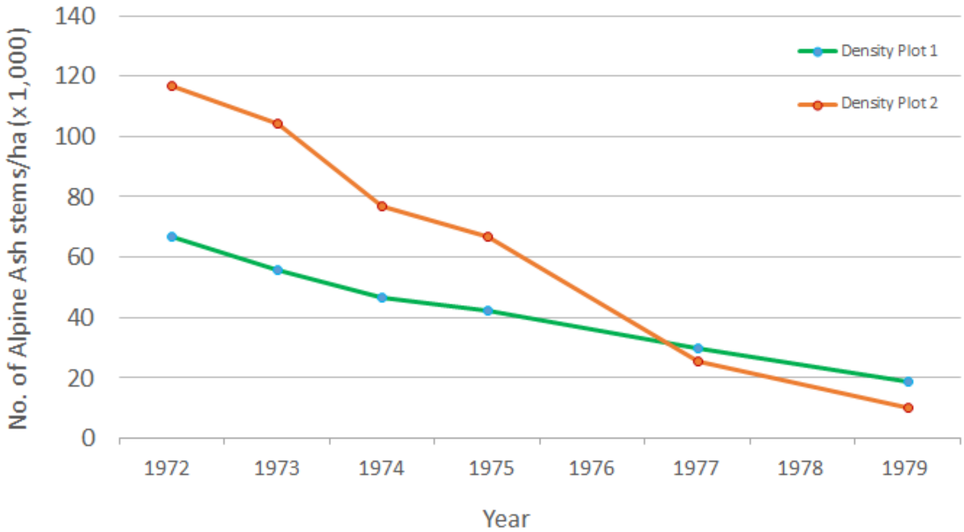

Figure 7. Seedling density mortality from age 1-8 years, including all age classes, following aerial sowing on the Errinundra Plateau, East Gippsland (Fagg 1981). Conclusion: Alpine Ash self-thins very well.

Height, Diameter, and Age. Mature trees in Victoria range up to 60 m in height (Nicolle 2006). VicForests investigated 18 Alpine Ash trees on their Giant Tree database, due to their large diameters, but with heights ranging only 49-55m. Boland *et al.* (2006) reports that the species can grow to 90 m, but this is most likely in reference to the Tasmanian subspecies only (Nicolle 2006).

Diameters of most old growth trees range from 100-200 cm (Bowman *et al.* 2014; Prior & Bowman 2014), but larger trees do occur. For example, 16 of the 18 giant trees previously preserved in State forest by VicForests have diameters in the range 250-300 cm. The other two have the following measurements:

(1) 303 cm diameter with height 53 m, and

(2) 353 cm diameter with height 55 m.

All have dead tops from wind and snow damage, given their high elevation position (M. Ryan *pers. comm.*). Alpine Ash with diameters up to 300 cm were also measured in the Dargo and Tambo areas during the 2007 strategic seed crop assessment that followed the 2006/07 bushfires (O. Bassett unpubl. data).

Given that Alpine Ash is readily killed by fire in Victoria, including the older, larger individuals, bushfires have limited the maximum contemporary age to about 250 years.

1.3 Taxonomy and genetics

Alpine Ash (*Eucalyptus delegatensis*) is one of the tall tree species in the 'blue ashes' group, placed in the subgenus Monocalyptus, section Cineraceae, which also includes Silvertop Ash (*Eucalyptus sieberi*) and Snow Gum *(E. pauciflora*) (*Boland et al*. 2006). It was first described by R.T. Baker[8] (**Figure 8**) in 1900, although initially named *Eucalyptus gigantea* by Hooker f. in 1847.

Figure 8. Richard T. Baker[4], Botanist, circa the 1920s. Courtesy: National Herbarium.

The species name *'delegatensis'* is taken from the locality where the original type-specimen was collected[9]; being Delegate near the far-east Victorian-NSW border. Its common name refers to the perceived similarity of its timber to the Ash of the northern hemisphere (*Fraxinus*).

Boland (1985) divided Alpine Ash into two sub-species: *Eucalyptus delegatensis* ssp. *delegatensis* (the mainland form) and *E. delegatensis* ssp. *tasmaniensis* (the Tasmanian form) mainly on the basis of leaf morphology. The Tasmanian form also differs visually in its bark persistence, the glandular-warty stems on seedlings and orbicular juvenile leaves.

Up to the 1970s, seed was freely transferred around the State (FCV 1968). But it was thought at the time that some seed-lots may not be adapted to sites at distance from their source, resulting in loss of growth and tree quality (Pederick 1990). Two Alpine Ash provenance trials were therefore established in the Mansfield area during 1979. The objective of a provenance trial is to test the hypothesis that precise matching of genotype with site being regenerated is required to obtain a healthy vigorous forest. The first trial was established using seed collected from altitudinal gradients along the four principal aspects around Mt Stirling, but no conclusions could be drawn from this trial, including that the strength of dormancy seemed unaffected by elevation (L. Pederick pers. comm.).

The second trial was established using seed collected by the CSIRO Division of Forest Research. This latter trial was established at Toombullup and Bindaree where seedlings were planted in ripped lines 3m apart. At 11 years of age, the mainland provenances had a better survival rate (77-81%) than the Tasmanian provenances (54-38%). Generally, the best growth was derived from provenances in North-east Victoria (Pederick & Bail 1991).

Later research confirms that Alpine Ash forests across Victoria share similar genetic characteristics, except for East Gippsland and Mt. Macedon (Neville *et al.* 2014).

[8] Richard Thomas Baker (1854-1941), after emigrating from England in 1879, became curator and economic botanist of the Sydney Technological Museum in 1898. (Wrigley and Fagg 2010).

[9] Type-specimen: Mt. Delegate, NSW, Jan 1899, *W. Bauerlen s.n.* (lecto: NSW) *fide* Boland (1985).

1.4 Timber qualities and products

The heartwood of Alpine Ash is pink or pale yellowish brown (**Figure 9**), and the sapwood is not clearly distinguishable. The grain is usually straight but can be wavy or produce a fiddleback figure. Growth rings are conspicuous. The sapwood is not susceptible to Lyctus borer, but Ambrosia (pin-hole) borers can leave dark stains in a sawn board (Bootle 2005).

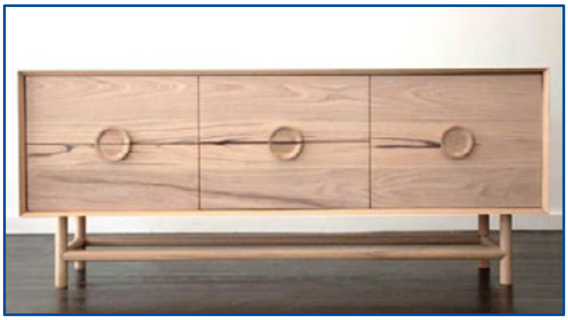

Figure 9. (Left) An heirloom quality sideboard made from Alpine Ash, showing wavy grains and browner tones; courtesy INGRAIN, Preston Victoria. **(Right)** An Alpine Ash straight-grain board used for flooring, BRITTON TIMBERS, Dandenong Victoria. 'Victorian Ash' has been quite popular for use in visual grade applications, given a particular pride in native timbers has developed in Australia.

For good quality boards it is usual practice to quarter-cut the log. Steam heating of partially dried timber and reconditioning in kilns to restore the original shape and to remove stresses, is normally required for the ash eucalypt species (Evans 1994, Bootle 2005). The term 'Tasmanian Oak' has been used by timber retailing businesses and may be either Alpine Ash, Messmate or Mountain Ash originating from Tasmania or Victoria. However, in recent years fine furniture makers had been calling this timber 'Victorian Ash' if accessed from Victoria.

On a scale of dry density, Alpine Ash is 680 kg/m^3 *c.f.* Red Gum 900 kg/m^3. The timber is not considered durable when in contact with soil (Bootle 2005). However, the timber of Alpine Ash is still relatively strong, and uses include flooring, architraves, veneers, fine furniture (**Figure 9**), plywood, rowing oars, handles, general construction, and paper-making.

In 1936 a pulp and paper mill (APM) was established at Maryvale, near Traralgon in Gippsland, to utilise eucalypt logs that were not sawlog quality. Alpine Ash has been valued for wood pulp as it has light colouring, low lignin content, and blends well with long-fibred pine pulp. As of 2022, this mill[10] was still operating but was the only mill left in Australia producing quality white paper at the time[11]. They also produce brown wrapping paper and cardboard which are now both in high global demand for packaging of internet sales.

[10] Now owned and operated by Opal Australian Paper, but no longer producing quality white paper.

[11] Including some which is made from recycled paper.

2. History of Forest Use

2.1 Indigenous people in Victoria's High Country

Prior to the arrival of Europeans, Aboriginal Australians occupied the land for over 50,000 years (Rasmussen *et al.* 2011)[12], primarily using coastal environments, woodland and lowland plains and forests for shelter and subsistence. Their use of natural resources was instinctive, and included the utilisation of small-size wood and bark products for shelter, utensils, canoes and weapons. Fire was used as an effective tool to assist hunting and, alongside fires started by lightning, helped fashion the nature of Australia's forest environments, including the floristics, extent and distribution of the wetter forests like Alpine Ash (Griffiths 2001).

Several Victorian Aboriginal clans[13] frequented Alpine Ash forests in summer, passing through on their way to the High Country (Johnson 1974). Here they gathered to strengthen human bonds with activities such as storytelling, knowledge sharing and ceremony (Ungunmerr Baumann 2020). While there, the people feasted on the Bogong Moth (*Agrotis infusa*) which congregated by night in rocky outcrops. Griffiths (2001) also found evidence that wetter forests may have been visited in the winter to forage for food, including the 'heart' of tree-ferns, and Lyrebird feathers for ornamental clothing.

2.2 Harvesting and milling history

After being first formally recognised and named by the European colonists in 1847 (**Section 1.3**), the tall, straight nature of Alpine Ash began attracting the attention of timber getters. In the early 1900s, logs of Alpine Ash were difficult to access in the mountains, and only individual trees would have been 'selected' then hand fallen (**Figure 10**) and removed by a bullock or horse team for hand-processing, or later by milling.

Figure 10. Axemen hand-falling a large 'Woollybutt' using boards to access the stem above the buttress. Image 'Australian Mountains' (2015) website.

Two major technological advances, steam-powered winch to haul logs and drying of partially dried timber in kilns, meant that accessible Alpine Ash and Mountain Ash forests were harvested more intensively for timber from about 1910. The use of steam

[12] https://www.australiangeographic.com.au/news/2011/09/dna-confirms-aboriginal-culture-one-of-earths-oldest/

[13] Including the Dhudhuroa First Nations peoples and Taungurung First Nations peoples.

winches and other expensive and immobile machinery, such as skyline systems, in mountain country meant that timber harvesting operations had to be intensive.

Prior to the vast 1939 bushfires, sawmills were established deep in the forests, and tramways were developed as a cheap, efficient and year-round means of conveying timber to the nearest railway station (**Figure 11**). Evans (1994) describes in detail how sawn timber was shifted by bush tramways from the Rubicon State Forest to the rail head at Alexandra.

Figure 11. (Above) Ezard's locomotive at the rear of a train of Ash logs from the slopes of Mt Erica heading to their bush-mill, circa 1938. Image FCV in McCarthy (1983).

(Left) A Shay locomotive on a trestle bridge near The Bump tunnel, Powelltown district, circa 1927. Image: Richards (1928) republished on the 'Australian Mountains' (2015) website.

Ash forests were 'clear-felled' primarily due to economic and safety factors. However, limited pulp was taken in the early days, with the first small but commercial supply to APM in 1938 (FCV 1967). This often resulted in forests being 'cut-over[14]' with a high residual basal area remaining. In the absence of a large pulp market and clear silvicultural knowledge, regeneration outcomes were not ideal and the Forests Commission Victoria (FCV) undertook research[15] to improve outcomes, with FCV annual reports providing an interesting read.

Crawler tractors were introduced in the 1930s and chainsaws started to replace hand-sawing and axes in the 1940s, although the effectiveness of the chainsaw was not fully developed and utilised until the 1960s (FCV 1967).

The devastating fires of 1939 killed most of the remaining mature forests and led to extensive areas of regrowth forest. Although not as extensively salvaged as Mountain Ash, some burnt Alpine Ash forests were salvaged from 1939 to 1951 (Moulds 1991, Evans 1994).

[14] Meaning; the best sawlogs taken, as in 'sawmiller selection'.
[15] A significant component of silvicultural research was overseen in the early years by Dr. Ron Grose.

The housing boom after World War II put more pressure on the forests for timber framing. Although some sawmills were rebuilt in the forest after the 1939 fires, many were rebuilt in nearby towns, thus necessitating the increased transport distance of logs to the mills by trucks and the construction of longer road networks. Other developments included increased mechanisation and larger sawmills.

For the period 1945-75, logging equipment essentially consisted of bulldozers that were used to open access tracks, snig (drag) logs to the landing, then help with de-barking and loading trucks from a bush ramp. High-lead logging, being the use of overhead cables, was practised in some Alpine Ash forests in steep terrain until the late 1960s (**Figure 12**).

Figure 12. (Left) Peter Fagg in 2016 inspecting a preserved winch known as "The Washington" which was part of a high-lead logging system in Alpine Ash forest on the Nunniong Road, Swifts Creek. **(Right)** Mick Hansby in 2020 doing the same in Alpine Ash forest along Pine Track in the Blue Range, Rubicon.

Rubber-tyred 'skidders' with winches were trialled in the 1970s (**Figure 13**), and were in wide use by the 1980s for snigging logs to landings, later employing grapples. After 1990, 'crab-grab' excavator-based machines were becoming common on landings for de-barking and loading logs, obviating the need for ramps. Saws were added for the docking of log-ends to correct length for transporting to processing mills (**Figure 13**).

By the mid-1990s, mechanical tree-felling heads on tracked excavator bases were being used in felling of 1939 regrowth, and this method, since about 2010, had virtually eliminated hand-falling due to safety and efficiency reasons. Excavators also 'shovelled' logs to the landing. All logs were removed from a coupe in integrated sawlog/pulp harvesting operations, with the sawlogs placed into 4-5 grades based on the extent of defects such as knots, rot and termite attack. The use of shovel logging along corded and matted snig tracks to a corduroyed landing is an advanced form of harvesting designed to protect soils and it enabled operations to continue during wetter periods.

Some mechanical thinning of 1939 Alpine Ash fire regrowth occurred in the period 2000-2005, mainly using the ‘outrow and bay’ technique at Nunniong and Matlock (Fagg 2006). Feller-bunchers and forwarders limited the amount of damage to the remaining trees. Aspects of commercial and pre-commercial thinning of ash regrowth species are described by Kerruish and Rawlins (1991) and Fagg (2006).

Prior to the closure of the Victoria’s native timber industry, about 750 ha of Alpine Ash was annually harvested by VicForests, out of 135,880 ha potentially available. During season 2020/21, the volume of sawlogs harvested from State forests totalled about 190,000 m^3 which was about 50% of the total sawlog volume of all eucalypts harvested that year.

Figure 13. (Above) A Timberjack 225 rubber-tyred skidder with winch and chains being trialled in Ash near Marysville in the early 1970s (FCV 1972).
(Right) A CAT 336D excavator with a Logfork 4 grapple head with saw managing Alpine Ash logs on a landing in the Central Highlands, circa 2020 (image: Hardwood Forest Products Australia).

Between 1989 and 2024, harvesting of all forests was governed by mandatory Codes of Practice, reviewed in 2022 (DELWP 2022). The Codes ensured that tree growing and timber harvesting were compatible with the wide range of environmental and social values associated with State forests at the time.

2.3 Silvicultural research and development in Alpine Ash

Dr. Ron Grose, in the late 1950s and early 1960s, was the first Victorian scientist to undertake extensive investigations into Victorian Alpine Ash silvics and silviculture. Ron pioneered the seed supply and aerial sowing techniques, laying the foundation for further developments that have been ongoing to the present day. Other early research into the silviculture of Tasmanian Alpine Ash was carried out in the period 1960-75 (Ellis & Lockett 1991), and built upon by Dr. Rod Keenan in the 1980s (e.g. Keenan & Candy 1983) and Dr. Michael Battaglia in the 1990s (Battaglia & Reid 1993a, 1993b; Battaglia 1993, 1996). However, in the main, regeneration issues in that state were different to those in Victoria, for example; ‘growth check’, where most seedlings after clearfelling would stop growing for some years.

In response to adopting a clearfell system of harvesting, and the need to regenerate, the seed characteristics of Alpine Ash in Victoria were identified after detailed research by Grose (1963, 1965). His field work, which later formed the basis of his Ph.D., was conducted in the Mansfield District, north-east Victoria (Grose 1957, 1960a and 1960b, see also **Section 3.3.1**).

Aerial sowing of Alpine Ash seed was pioneered in 1964 with light, fixed-wing aircraft (Grose *et al.* 1964). In those days, the Forests Commission of Victoria (FCV) trialled a number of seed coating products to assist delivery and most aerial sown seed was coated with kaolin (**Figure 14**). Helicopters, which were known to provide greater manoeuvrability and sowing accuracy, were trialled on small areas as early as 1966 (FCV 1967), but their higher costs meant they did not become routine until the 1990s (Wallace *et al.* 1995). Interestingly, fixed-wing Air Tractors were again utilised for the first time since the 1990s to sow large areas (50-500 ha) following the 2020 Black Summer bushfire, leaving helicopters to sow areas <50 ha (**Figure 15**) (Bassett *et al.* 2021).[16] (see **Chapter 7** for more detail).

Figure 14. (Left) Aerial sowing of seed coated with Kaolin onto a 'cut-over Ash forest' following burning during autumn 1969. It is the Kaolin that created the dusty trail. **(Right)** Alpine Ash regeneration on a different coupe being inspected in 1968 at age two years, resulting from some of the earliest aerial sowings undertaken in Victoria (Images: FCV annual report 1968/69, FCV 1969).

Given the early intensive work by Grose, the silviculture of Alpine Ash was considered better understood by the 1980s (Campbell *et al.* 1984). However, changes were coming, both socially and climatically that would test forester's understanding of the species. In response to ongoing controversy regarding the clear-felling system, the Silvicultural Systems Project (SSP) was initiated in 1989 to compare alternative systems with clear-felling. The need for the SSP was also underlined by the lack of well-documented knowledge on the ecological, economic and social effectiveness of alternatives to clearfelling. Two sites were established, one in Mountain Ash at Tanjil Bren in West Gippsland, and the other in Low Elevation Mixed Species at Cabbage Tree Creek in East Gippsland. An Alpine Ash component was planned in the Rubicon State Forest, NE Victoria, but was never established. The results of the Mountain Ash

[16] Using this mix of aircraft types was redeveloped by Bryan Nicholson (formerly VicForests) to overcome VicForests' enormous challenge of sowing 11,500 ha by close July 2020 (see **Chapter 7**).

component were documented by Dr. Rob Campbell, Dr. Ross Squire and others (CFTT 1997; Van Der Meer & Dignan 2007), and to some extent can be applied to Alpine Ash regrowth forests of 1939 origin, given their similar forest dynamics.

Figure 15. (Left) Airborne: Helicopters are now routinely used for sowing eucalypt seed, seen here sowing into fire-killed Alpine Ash during 2020. However, fixed-wing aircraft **(Right)** were reintroduced in that same year to assist with the extensive post-bushfire sowing (Images: Forest Solutions).

The research objectives of SSP were to understand eucalypt seed biology and supply, seedbed formation, seedling establishment, and growth and stand development under a range of silvicultural systems. This work led to improved silvicultural practices and assessment techniques, with many findings incorporated into the State's *Native Forest Silviculture Guideline* series; which historically guided silvicultural operations associated with timber harvesting and now guides the State government in forest restoration.

Dr. Brian Turner, Dr. David Flinn and others (Turner *et al.* 2011) collated a large number of references in their review of science, including Alpine Ash, underpinning the management of Victoria's commercial native State forests. Mark Lutze, Dr. Rob Campbell and Peter Fagg, in Lutze *et al.* (1999), provide a good summary of the development of Alpine Ash silviculture in Victoria, alongside other forest types.

Major developments in the area of eucalypt flowering and seed crop assessment resulted from SSP, with contributions from Murray Harrison, Owen Bassett and others, initially under the guidance of Dr. Rob Campbell for Mountain Ash (e.g. Harrison *et al.* 1990) and Peter Geary for Low elevation Mixed Species (*e.g.* Bassett & White 1993). Work undertaken by Owen during SSP in East Gippsland, and based on the pioneering work of the late Dr. David Ashton (Ashton 1975a), was later applied to the Mountain Ash SSP component. Floral biological monitoring and forecasting techniques for flowering events and seed crops were developed to support forward planning (Bassett 2011), and have been applied every season since 1994 for Mountain Ash and since 2002 for Alpine Ash (Bassett 2023). The data sequence for Alpine Ash has been unbroken for 22 years (**Box 8 & Section 4.1.2**).

To accompany flowering and seed crop forecasting, aerial assessment and mapping of flowering (**Figure 16**) has been utilised and applied annually in Alpine Ash since 2002. The technique was first developed by Bill Incoll (Incoll 1974), and is now refined and regularly used by Forest Solutions to assist Victoria's State government with eucalypt seed management in Ash forests (Bassett 2011; Bassett 2023) (see **Chapter 4**).

In response to ongoing social perceptions about clearfelling and slash-burning, and the need to develop systems which cater for high conservation values (HCVs), VicForests further developed the timber harvesting silviculture of Alpine Ash to include more intensive assessments of HCVs and higher levels of overwood to support multi-cohort forest management. Overwood can be aggregated in patches or retained as dispersed individuals. To reduce the mortality of this retained overwood, VicForests investigated alternative site preparation techniques to high intensity slash-burning, including cooler burns and different types of mechanical soil disturbance (VicForests 2019) (see **Chapters 5 & 6**).

Figure 16. **(Left)** Airborne: Alpine Ash flowering in State forest near Mt Phipps, Gippsland, during an aerial assessment to map the extent of flowering in 2023.
(Left image: Forest Solutions).

(Right) A Cessna 337G Skymaster, being the twin engine fixed-wing aircraft now used by Forest Solutions to assess flowering in the Ash species across eastern Victoria.
(Right image: courtesy of Daryl Chibnall, Aerovision).

A more advanced understanding of Alpine Ash fire ecology occurred recently following two decades of multiple, short-interval bushfires, induced by significant drought periods; first the millennial drought spanning 1997-2009, then two shorter and more intense droughts around 2014 and 2018. The response of Ash forests to frequent fires and options for forest management were investigated by academics, Dr David Bowman (e.g. Bowman *et al.* 2014), and Dr. Thomas Fairman, Dr. Craig Nitschke and Dr Rod Keenan (e.g. Fairman *et al.* 2016; Keenan & Nitschke 2016), and in the applied native silviculture sector by Peter Fagg, Owen Bassett, Mark Lutze, Carolyn Slijkerman, Wally Notman and others (e.g. Lutze & Terrell 2000; Fagg *et al.* 2013; Bassett *et al.* 2015; Slijkerman *et al.* 2024). Techniques for rapid-response assessment and silvicultural treatment of fire-killed Ash following bushfires were developed by the applied silviculture team (Poynter *et al.* 2009). The technique determines if and where intervention by aerial sowing is required in the landscape, and includes the use of seed forecasting, fire intensity mapping, and rapid forest damage and seed bed assessments by age class. The most recent applications occurred during the 2018 to 2020 period (Bassett & Galey 2018, 2019; Bassett *et al.* 2021) (see **Chapter 7** for details).

2.4 Alpine Ash forest in National Parks

The history of Park creation *involving Alpine Ash forests* has very early beginnings in Victoria and developed momentum following the National Park Act of 1975 (Table 2). Mount Buffalo was one of Victoria's earliest National Parks; previously made famous as a tourist resort by personalities and outdoor clubs of the time (**Figure 17**. Barrett 1924; Johnson 1974).

Figure 17. (Left) 'Guide Alice' Manfield, an early personality who encouraged tourism at Mt. Buffalo which became Victoria's first National Park containing Alpine Ash. Guide Alice took tourists to see Lyrebirds (**Section 3.1.4**).

(Right) The Buffalo Gorge with its narrow, dirt access road to the Park in the 1920's, just below the Alpine Ash forest (both images: Barrett 1924).

Since the 1960s, land and forest-resource use in Victoria has been well contested, with strong, often polarised political and social forces shaping the boundaries of land tenure and defining forest use (Poynter 2018; Walker 2021). Victoria's forests are rich in values and resources that benefit people, their communities, and the environment. Although no longer available, native timbers were historically harvested from State forests, and people enjoyed their wood properties, applications, and renewable status.

National Parks exist alongside State forest to ensure there are areas of biodiversity that are less intensively impacted. The area of forest inside Victoria's Parks now contains an adequate representation of most pre-European era forest-types, especially the tall wet/damp forests of Alpine Ash. **Table 1, Section 1.2** indicates that 154,000 ha of Alpine Ash forest occurs in Parks and reserves[17]; contained mostly in the Alpine National Park, but also in the Snowy River, Mount Buffalo, Baw Baw, and Yarra Ranges National Parks.

Significant areas of Alpine Ash were being gazetted as National Park by the early 1980s, with conservationists of the time applying the tenure change as their mechanism for ongoing protection (Poynter 2018). The Bogong and Wonnangatta Parks were eventually combined into a larger Alpine National Park in 1989, bringing areas of

[17] An accurate area of Ash species in Park is unavailable. Most data for vegetation inside National Parks is only EVC modelled, and post-fire analysis by Forest Solutions after the 2013, 2018, 2019 and 2019/20 bushfires identified additional areas of Ash forest present in each fire extent inside the Alpine and Snowy River National Parks not formally mapped (Bassett *et al.* 2015; Bassett & Galey 2018, 2019; Hansby & Bassett 2020; Bassett *et al.* 2021).

regrowth Ash that had regenerated following earlier 'once-only logging' into the Park. Many of these old timber coupe areas can be seen today at age 50 to 60 years supporting healthy eucalypt regrowth, an established understorey, and functioning similarly to unharvested forest of the same age.

Table 2. History of the key National Parks that include Alpine Ash forest in Victoria. There may be other smaller areas in Parks not listed here (source: Victorian National Parks Association and Parks Victoria).

Year created	Region	Name of National Park	Area (ha)
1898-1908	NE Victoria	Mount Buffalo (expanded)	1,000 to 10,000
1979	West Gippsland	Baw Baw	13,000
	East Gippsland	Snowy River	26,000
1980	NE Victoria	Mount Buffalo (expanded)	31,000
1981-82	Victorian Alps	Bogong	81,000
		Wonnangatta	107,000
1988	East Gippsland	Snowy River (expanded)	54,000
		Errinundra	25,000
1989	Victorian Alps	Alpine (incl. Bogong and Wonnangatta above)	647,000
1995	Central Highlands and Dandenong Ranges	Yarra Ranges (incl. water catchments)	76,000
2010	East Gippsland	Snowy River (addition)	29,000
		Errinundra (addition)	

While the National Parks excluded timber harvesting, fire does not respect tenure boundaries. In the last three decades, since the Caledonia Bushfire in 1998[18], Alpine Ash forests in National Parks have been impacted by several intense, short-interval bushfires on average four years apart, with some areas burning multiple times prior to reaching reproductive age. The species is therefore at risk of local type-change to a different or non-forest state where this occurs (Fairman *et. al.* 2016). Following fires in 1998, 2003, 2006/07 and 2009, Parks Victoria did not aerially sow fire-killed Ash. However, the implications of ongoing bushfires encouraged further consideration from Park managers following the 2013 Harrietville-Alpine bushfire, perhaps due in part as a response to climate change, but also the realisation of the evolving scale of the bushfire problem. At that time, Parks Victoria therefore enabled forest recovery action from other State government agencies and the private forest sector to sow an area of 1,857 ha inside the Alpine National Park[19] (**Figure 18**; Bassett *et al.* 2015). Such active management of <u>all</u> Ash forests, regardless of tenure, is critical for conservation (Poynter 2018, see this Manual's **Foreword**).

[18] Heyfield fire No. 31 in 1998; also known as the 'Carey State Forest bushfire', but which notably burnt more National Park area (25,000 ha) than State forest area (9,600 ha) (Lutze & Terrell 2000).

[19] Only 198 ha required sowing in State forest.

Figure 18. Airborne: An historic moment - aerial sowing Alpine Ash seed from a helicopter inside the Alpine National Park near Mt. Freezeout, south west of Mt. Hotham, on the 26th June 2013. The white dead stems are mature Ash killed by the 2006/07 bushfire, from which seed had fallen to produce the regrowth that was later killed in 2013, leaving the site with no natural source of seed. Aerial sowing ensured the continued presence of Alpine Ash in sown areas (Image: Forest Solutions).

Since then, Parks Victoria has participated in all recovery programs following bushfires in 2018 and 2019, and particularly following the unprecedented fires of Black Summer in 2019/20 (Bassett & Galey 2018, 2019; Bassett *et al.* 2021).

The stated position of Parks Victoria management after the 2018 Tamboritha-Dingo Hill Track bushfires, which occurred entirely inside the Alpine National Park, included:

- Understanding the impact of bushfire on the persistence of the Ash forest-type is important to Parks Victoria, particularly where forest-type change is predicted to occur, and options for silvicultural intervention will be considered.
- Visitor experience and satisfaction is a critical factor influencing park management decisions, and any forest-type change or loss may impact this.
- Geo-hydrological issues following bushfires are also a factor. Flash-flooding following bushfires can cause severe erosive damage and impact water quality[20], with revegetation of denuded slopes important for minimising such impacts in the mid to long term.

The area of young Alpine Ash regrowth in Park that remains vulnerable to future bushfires is growing. Fairman (2022) reports an estimated 181,000 ha of immature Ash in Victoria, which will reduce to about 83,000 ha by 2024 if no further fires occur. By 2030, an estimated 45,000 ha of immature Ash will exist in Park and 26,000 ha State forest. In response to this, and the expected increasing bushfire frequency, Parks Victoria are responding (see **Box 1**).

[20] Flash-flooding is known to occur (Nyman *et al.* 2011) and was experienced firsthand following the 1998 Caledonia and 2006/07 Great Divide bushfires, endangering the lives of fire-fighters. One life was lost in 2007.

Box 1. Parks Victoria’s Alpine Ash fire risk mitigation project

During 2018/19, in response to the growing risk posed by fire to Alpine Ash forests across all tenures (**Figure 19**), Parks Victoria (PV) partnered with University of Melbourne to develop prioritisation tools to help guide post-fire rapid forest recovery operations (Huguenin *et al.* 2019). The resulting prioritisation model considers current and future condition and extent of Alpine Ash forests by age-class in response to predicted climate change, bushfire scenarios and potential management interventions. The modelling provides an output of mapped distribution of predicted Alpine Ash ‘landscape refugia’ that are less likely to experience frequent bushfire, and conversely, a mapped distribution of Alpine Ash more likely to experience forest type-change due to short-interval bushfire regimes (Nitschke 2019).

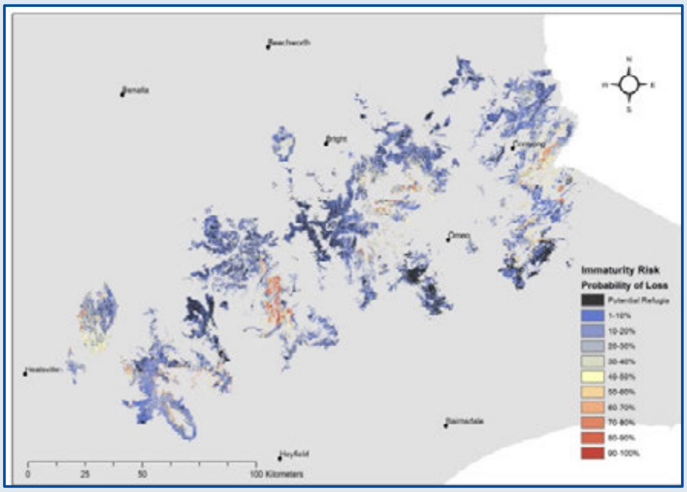

Figure 19. (Left) Double burnt Ash looking south from the Great Alpine Road at the Mount St. Bernard VicRoads depot, 2013.

(Right): an example of mapped immaturity risk for Alpine Ash, showing probability of loss (prepared by Craig Nitschke, University of Melbourne).

Following the 2019/20 Black Summer bushfires, PV’s risk mitigation model was applied to prioritise sowing of immature fire-killed Ash in fire refugia zones, based on the prediction that resulting regrowth has a high probability of survival (Bassett et al. 2021; Figure 19). This approach is warranted, given fire recovery efforts during the Macalister fires of 2019 were re-sowing areas that had been previously sown in 2013 and recovered following earlier bushfires, but then burnt again to trigger the second sowing. Areas of refuge were also becoming obvious in 2019, having escaped the 1998, 2007 and 2019 bushfires (Bassett & Galey 2019). It is currently untested if Nitschke’s model predicts these known refuge areas accurately, with further work required over time to validate the effectiveness of the model.

3. Ecology of Alpine Ash Forests

3.1 The Alpine Ash ecosystem

For the purpose of this Manual, referring to the 'Alpine Ash' forest type' regarding *Eucalyptus delegatensis* generally means forests with an overstorey dominated by trees of this species. While Alpine Ash forests can occur in pure stands, there is considerable variation that occurs across its range - in terms of the species which make up the overstorey, with 'mixed stands' of Alpine Ash including species like Mountain Gum (*E. dalrympleana*). Other common lifeforms include understorey trees and shrubs and the faunal species typical of the forest type. This chapter will address some of that variation and diversity.

In comparison to Mountain Ash (*E. regnans*), the other major Ash-type eucalypt in Victoria (see **Chapter 1**), there has been a smaller research focus on Alpine Ash. While some aspects of its ecology have been intensively studied, such as regeneration conditions (e.g. Grose 1963), other aspects are less well known. There has also often been a tendency in ecological research efforts to group Alpine Ash with Mountain Ash and Shining Gum (*E. nitens* or *E. denticulata*) into the broad 'montane ash' category (e.g. Lindenmayer *et al.* 2000). The result of this is that insights largely relevant to Mountain Ash forests are generalised to Alpine Ash forests, which tends to move our focus away from the distinctive and/or critical, characteristics of Alpine Ash. This approach risks missing new discoveries that would otherwise further our understanding and help refine our management of the species.

This Chapter therefore summarises current ecological knowledge of Alpine Ash forests, focussing on the following key aspects:

1. Climate that is common to the distribution of Alpine Ash;
2. Vegetation communities and flora associated with Alpine Ash forests;
3. Fauna and important habitat characteristics of Alpine Ash forests, focusing predominantly on birds and arboreal mammals; and
4. Ecological dynamics of Alpine Ash forests following natural disturbances, both biotic and abiotic.

3.1.1 Climate and distribution

The general distribution of Alpine Ash within Victoria is described in **Section 1.1**.

In summary here, Alpine Ash has a wide distribution in high elevations areas, generally at elevations between 900-1500 m in Victoria (see **Figure 3** on page 3). Snow can be present in Winter and Spring, and frost incidence is moderate to high, with 50 to 100 frosts each year (Boland *et al.* 2006). Alpine Ash forests are typically cool and humid and found in areas where the hottest months range from 19-25˚C and coldest months range between -4˚ to 3˚C (**Figure 21**). Annual rainfall (also **Figure 21**) ranges from 700 to 2500 mm per annum, with winter rainfall dominant (Boland *et al.* 2006). Fog-drip and condensation can supplement rainfall and is known to assist survival of young seedlings during extended dry periods following high severity fire (Bassett & Pryor 2014; **Figure 22**). At the lower ends of its elevation, at say 800 m to 900 m, Alpine Ash may be found on cooler and wetter aspects, or more sheltered sites where cold air drainage or frost is more likely. In Victoria, Alpine Ash occurs on well-drained and deep soils commonly derived from sediments and granites (Boland *et al.* 2006). Alpine Ash transitions to other eucalypt forest-types at its elevational extremes, such as Mountain Ash at the lower ecotone (Flint and Fagg 2007), and sub-alpine vegetation at the higher ecotone; often with Snow Gum (FCNSW 1986; Boland *et al.* 2006; see **Section 1.1**).

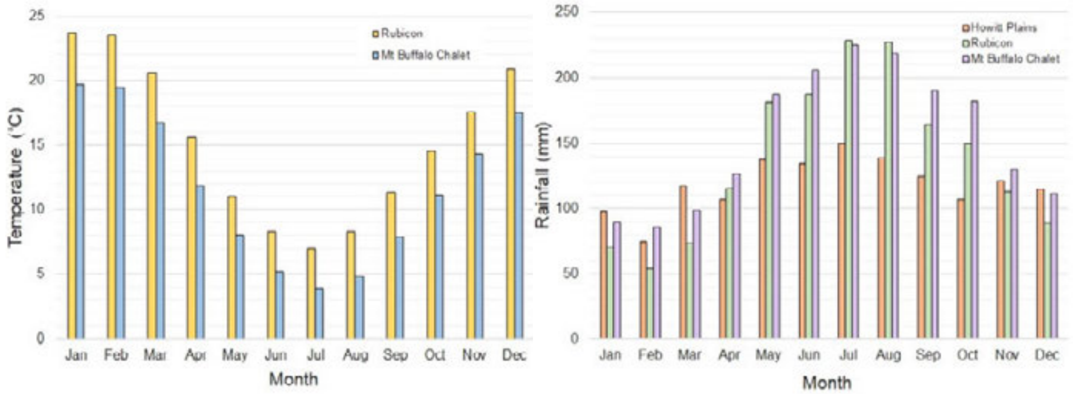

Figure 21. Mean monthly temperature (left) and rainfall (right) for Bureau of Meteorology weather stations near Alpine Ash. These weather stations are indicative of the general climate associated with Alpine Ash forest – only the Rubicon station is 'embedded' in Alpine Ash forest. Note that both the Howitt Plains and Mt Buffalo Chalet weather stations have been operational since 2011, but the Rubicon SEC weather station ran from 1943 to 1993. Temperature is not available from Howitt Plains.

Figure 22. Two Alpine Ash seedlings, photographed at different sites within a 30 minute window, during a dry period in 2013 in the Upper Dargo. **(Left)** This seedling is healthy due to condensing fog and fog-drip off standing dead Ash. The other seedling nearby **(at Right)**, but lower down-slope, is stressed due to drought, with neither rain nor fog present to ameliorate dry conditions. (From Bassett & Pryor 2014).

3.1.2 Forest structure, flora and vegetation communities

The forest structure of Alpine Ash is typically 'tall-open forests' (Specht, 1970), which takes form in a range of ecological vegetation communities discussed below. As a mature tree, Alpine Ash has fibrous bark covering the lower half of the trunk (see **Figure 1**, **Chapter 1**). The mainland subspecies has a poor ability to vegetatively recover[21] when the stem is impacted by severe fire. Alpine Ash does possess epicormic buds which can sprout following fire if the tree is not killed (**Figure 23**), but this is rare following intense fire and usually only occurs where the bushfire has burned 'cool'. Seed is the primary source of regeneration, and Alpine Ash is therefore referred to as an 'obligate seeder' (Bowman *et al.*, 2014). The relationship between Alpine Ash and fire is covered in **Sections 2.3 & 3.2** (see also **Box 1**).

Figure 23. A crown-burnt mature Alpine Ash found by O. Bassett to be resprouting from an epicormic bud near Marysville following the 2009 Black Saturday bushfire.

Given Alpine Ash is widespread, the species occurs in many bioregions across Victoria: the Northern and Southern Falls of the Highlands, Highlands Far East, the East Gippsland Uplands, the Monaro Tablelands and the Northern Inland Slopes, with the majority occurring in the Victorian Alps bioregion. This range means there is high variability in site productivity, forest structure and environmental conditions; with heights up to 60 m in Victoria (Mifsud & Harris 2016) and a dispersed density in some locations, depending on site and disturbance history.

Five floristic communities and 29 forest subtypes of Alpine Ash forest have been identified from an analysis of Alpine Ash vegetation communities using 548 quadrats collected from 1974 to 1989 (Mueck, 1990).

Three of these floristic communities are either highly restricted to certain regions or are not strictly dominated by Alpine Ash (Mueck, 1990). The two widespread Alpine Ash floristic communities are as follows:

(i) **Montane Forest:** Tall open-forest in sheltered sites in montane areas; dominated by Alpine Ash, but associated canopy species may include Shining Gum (*E. nitens or E. denticulata*), Snow Gum (*E. pauciflora*), Mountain Gum (*E. dalrympleana*), Candlebark (*E. rubida*), Broad-leaved Peppermint (*E. dives*), Narrow-leaved Peppermint (*E. radiata*) and Bogong Gum (*E. chapmaniana*), and

[21] Resprout from epicormic buds along the stem or from a basal lignotuber.

(ii) **Montane Riparian Forest:** Tall open-forest restricted to riparian areas in montane environments. Associated overstorey species include Manna Gum (*E. viminalis*) and Mountain Gum (*E. dalrympleana*); understorey is often dominated by Mountain Tea-tree (*Leptospermum grandifolium*).

An overstorey including Alpine Ash is the common feature of these floristic communities, with different assemblages of understorey species accounting for the major differences.

In the development of Ecological Vegetation Classes (EVCs DEECA 2022), Montane Forest was split into two EVCs – *Montane Damp Forest* and *Montane Wet Forest*. The former typically includes an overstorey mix of Alpine Ash with co-occurring other eucalypt species (e.g. Mountain Gum), and the latter can be a mix of Alpine Ash and Mountain Ash overstorey and predominantly occurs in the Central Highlands (**Figure 24**). Montane Damp Forest and Montane Wet Forest are not the only EVCs which contain Alpine Ash. Other EVCs which may include Alpine Ash in some proportion include: Tableland Damp Forest; Montane Herb-rich Woodland; Wet Forest; and Shrubby Wet Forest. Note that Alpine Ash only features in these EVCs in some bioregions (e.g., Wet Forest in the Victorian Alps has both Alpine Ash and Mountain Ash in the overstorey, but Wet Forest in Highlands Southern Fall only has Mountain Ash).

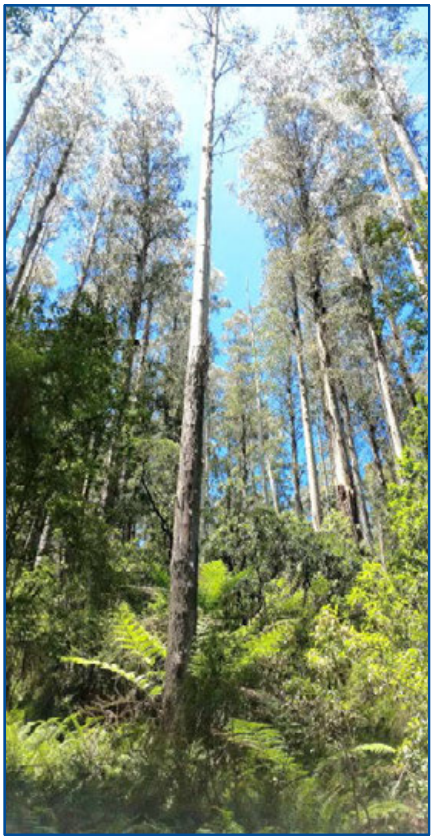

Figure 24. Tall Montane Wet Forest with Alpine Ash (foreground) and Gum species and Ash in the background in the Central Highlands.

Understorey species composition

There is a range of understorey species which co-exist with Alpine Ash, giving rise to a range of forest subtypes. There are broad and complex relationships that develop between biotic and abiotic factors, including disturbances such as fire, which make generalising the drivers behind the occurrence of particular understorey species and forest subtypes difficult. Mueck (1990) indicated that for the closely related Mountain Ash forest, the dominant environmental gradient governing floristics was moisture. In Alpine Ash forest, this is also a factor but elevation and disturbance history can also influence floristics. Due to this, the floristics of Alpine Ash forests in the west and east end of its distribution in the state of Victoria can differ noticeably.

There are, however, a number of species which are found across the range of Alpine Ash forests – these include the Tasman Flax-lily (*Dianella tasmanica*), Mountain Hickory Wattle (*Acacia obliquinervia*), Elderberry Panax (*Polyscias sambucifolia*), Rough Coprosma (*Coprosma hirtella*), Hop Bitter-pea (*Davesia latifolia*), Mountain Correa (*Correa lawrenciana)* and Mother Shield-fern (*Polystichum proliferum*) (Mueck 1990; Wagner and Nitschke 2021). In the Central Highlands, species that are more abundant in mature Alpine Ash forests, compared to Mountain Ash, include ground ferns (*Blechnum sp.* and *Polystichum* sp.) and the shrubs Notched Leionema (*Leionema bilobum*), Mountain Pepper (*Tasmannia lanceolata*), Balm Mint-bush (*Prostanthera melissifolia*), Mueller's Bush-pea (*Pultenaea muelleri*) and Daisy Bushes (*Olearia sp*.) (Bowd *et al.* 2021;) (**Figure 25**).

Alpine Ash floral displays in State forest

Figure 25. Two understorey assemblages in regrowth Alpine Ash: **(Left)** in flower is Balm Mint-bush (purple), Snowy Daisy-bush (Olearia lirata; white) and Hop Bitter-pea **(Centre also)**. **(Right)** in flower is Mountain Hickory Wattle at Mt Stirling, NE Victoria. All images taken in December 2016.

On sheltered sites, Alpine Ash forest types can be relatively species rich, with substantial shrub cover and a high diversity of grass and herb species (Mueck, 1990), and mature Alpine Ash forests can have greater species richness than mature Mountain Ash forests (Bowd *et. al.* 2021). On more exposed sites (i.e., northerly and westerly aspects), species abundance and diversity is lower, with a dense shrub layer dominated by few pea or Acacia species such as Tall Oxylobium (*Oxylobium arborescens*), Alpine Podolobium (*Podolobium alpestre*), Hop Bitter-pea (*Daviesia latifolia*) or Mountain Hickory Wattle (*Acacia obliquinervia*). At drier sites, species such as Prickly Starwort (*Stellaria pungens*), Showy Violet (*Viola betonicifolia*) and Grassy Tussock-grass (*Poa sieberiana*) are more common; at wetter sites, species such as Banyalla (*Pittosporum bicolor*), Hard Water-fern (*Blechnum wattsii*) and Soft Tree-fern (*Dicksonia antarctica*) are more prevalent (**Figure 26**) (Mueck 1990; Bowd *et al.* 2021).

Disturbance and the age of the Alpine Ash stand also influences floristic composition. Studies of Montane Wet Forest in the Central Highlands, including Alpine Ash, found that in young regenerating stands (less than 10 years old) following high severity fire, graminoids such as Sword Tussock-grass (*Poa ensiformis*) and Tasman Flax-lily (*Dianella tasmanica*) are abundant, as well as a range of Acacia species (*Acacia nanodealbata* and *Acacia obliquinervia*) and shrubs (*Olearia phlogopappa*, *Pimelea axiflora*) (Bowd *et al.* 2021). In the Victorian Alps, multiple fires were found to increase the number of understorey flora species present. More than 90 species were recorded in Alpine Ash sites between Licola and Mt Hotham that were burned by two or three high severity fires between 1998 and 2020. In contrast, approximately 40 species were found in long unburnt Alpine Ash forests in the same region (Wagner & Nitschke 2021).

Figure 26. Hard Water-fern, with its rufous-coloured new growth in summer, and Soft Tree-fern below Alpine Ash in the Upper Yarra Catchment, Yarra Ranges National Park.

There are several possible reasons for this – fire will initiate germination of the long-held soil seedbank, or the frequency of fire may create more opportunities for certain species. However, at the landscape scale, more frequent fire reduced soil seedbanks and increased similarity between burned sites, suggesting that frequent fire may increase the number of species but also homogenise understorey plant composition (Duivenvoorden *et al.* 2024).

3.1.3 Birds – leading author: Richard Loyn

Alpine Ash forests resemble Mountain Ash forests in many respects, including their tall stature and tendency to regenerate as relatively even-aged stands after bushfire. However, they also differ in various ways that influence the use of habitat by fauna. Whereas Mountain Ash forests usually have dense middle storeys of tall shrubs and wattles, in Alpine Ash forests those structures are more variable, well represented in gullies and sheltered slopes but less so elsewhere. Dense understoreys of low shrubs or fern are often found in stands of Alpine Ash on upper slopes and ridges. This influences the resulting bird community: bird abundances and species richness tend to be somewhat lower in Alpine Ash, and the guild[22] compositions can be markedly

[22] A group of species that have similar requirements and play a similar role within a community.

different. For example, Table 3 highlights that mature Alpine Ash forests in the Upper Kiewa were found to be dominated by canopy-foraging insectivores, which constituted 34% of the bird community, compared with 11% in Mountain Ash of the Central Highlands (Loyn 1985). Similarly, nectarivores constituted 23% in Alpine Ash c.f. 11% in Mountain Ash. In contrast, insectivores that forage from tall shrubs constituted 6% of the bird community in Alpine Ash c.f. 26% in Mountain Ash, and insectivores that forage from damp ground below shrubs constituted 9% in Alpine Ash c.f. 24% in Mountain Ash (Table 3).

Table 3. Bird guild by food, and location for invertebrates, and selected bird species in Alpine Ash forests compared with Mountain Ash forests (from Loyn 1985). Data represent individual birds as a % of total bird community. Alpine Ash data is from East Kiewa, originally from Loyn & Woinarski (unpubl.).

Guild		**Mountain Ash**	**Alpine Ash**	**Bird species**
Main food		**Various ages (% of birds)**	**Mature (% of birds)**	**Examples in Alpine Ash**
Invertebrates	open ground	1.0	2.6	Flame Robin
	dense shrubs*	**24.0**	8.8	Pilotbird; White-browed Scrubwren; Superb Lyrebird
	shrubs + mid-storey	**26.0**	6.4	Brown Thornbill; Golden Whistler, Rose Robin
	all levels	13.0	12.0	Grey Shrike-thrush; Grey Fantail
	canopy	11.0	**34.0**	Striated Thornbill; Spotted and Striated Pardalotes
	trunk/branch	5.1	2.3	White-throated and Red-browed Treecreepers
Nectar or honeydew		11.7	**23.3**	Yellow-faced and White-naped Honeyeaters; Red Wattlebird
Fruit		3.3	3.3	Silvereye
Seeds/galls		2.0	3.0	Crimson Rosella; Gang-gang Cockatoo
Vertebrates		2.1	4.1	Pied and Grey Currawongs; Australian Raven

*including damp ground below shrubs or in spaces between shrubs and ground fern patches.

The twelve most abundant bird species in that Alpine Ash study, in descending order of abundance, were Yellow-faced Honeyeater then Striated Thornbill (**Figure 27**), Spotted Pardalote, Striated Pardalote, Grey Fantail, White-browed Scrubwren, Brown Thornbill, Grey Shrike-thrush, Red Wattlebird, Silvereye, Crimson Rosella and Flame Robin (**Figure 27**) (Loyn 1985). The abundance of Yellow-faced Honeyeaters in Alpine Ash was perhaps unexpected, given the species is a rare visitor to Mountain Ash forests where it only occurs spasmodically in years of peak flowering: its main habitat being mixed species forests. In summer the Yellow-faced Honeyeater visits high elevation forests, feeding extensively on insects in the eucalypt canopy as well as nectar from eucalypts[23] and mistletoes. Two other honeyeaters, Red Wattlebird and White-naped

[23] In Victoria, the peak of Alpine Ash flowering usually occurs in January (see **Chapter 4**)

Honeyeater, were also more common in Alpine Ash than Mountain Ash, and both feed extensively on insects gleaned from foliage as well as nectar. Loyn (1985) notably found another canopy-foraging insectivore, Rufous Whistler, to occur in Alpine Ash - albeit in small numbers - whereas it is extremely rare in Mountain Ash forests (Loyn 1985). A separate analysis of birds in Ash forests in the Central Highlands by Lindenmayer (2009) also recognised the high abundance of nectarivores in Alpine Ash compared with Mountain Ash, including Red Wattlebird, White-naped Honeyeater and White-eared Honeyeater.

Figure 27. Three bird species that frequent Alpine Ash forest in Victoria: **(left to right)** Yellow-faced Honeyeater, Striated Thornbill and Flame Robin. The Yellow-faced Honeyeater is the most common Honeyeater found in Alpine Ash (images: Richard Loyn).

Conversely, species that feed primarily among tall shrubs (e.g. Golden Whistler, Brown Thornbill, Large-billed Scrubwren, Rufous Fantail and Crescent Honeyeater), or from the damp ground below shrub cover (e.g. Superb Lyrebird, White-browed Scrubwren, Bassian Thrush, Eastern Yellow Robin, Olive Whistler, Eastern Whipbird and Pilotbird) were generally more common in Mountain Ash than Alpine Ash (Loyn 1985). However, all these species can occur quite commonly in stands of Alpine Ash where suitable shrub cover has developed, or in the case of Lyrebirds where there is sufficient open ground between this cover for feeding.

Some of the bird species mentioned above are summer visitors to Ash forests, even when they can be found throughout the year in foothill forests at lower altitudes. Many species are more common in summer than winter at the altitudes where Alpine Ash occurs (e.g. Gang-gang Cockatoo, pardalotes and Pied Currawong). Species that rarely remain in Alpine Ash forests over winter include Fan-tailed Cuckoo, Grey Fantail, Golden Whistler, Flame Robin, Rose Robin, Black-faced Cuckoo-shrike and Silvereye, as well as a group of species that are summer migrants to most forests in Victoria (e.g. Shining Bronze-Cuckoo, Tree Martin, Satin Flycatcher, Rufous Fantail and Rufous Whistler). All of these migratory species feed mainly on insects gleaned from the canopy or tall shrub foliage, whereas species that remain over winter in Ash forests are mainly those that feed on invertebrates from bark or damp ground below shrubs, with just a few insectivores remaining that feed in the canopy or shrub layers.

Other work in Alpine Ash near Mount Stirling (Macak *et al.* 2010) presents a similar picture, but Crimson Rosella was the most numerous species in that study and White-throated Treecreeper and Gang-gang Cockatoo also featured in the top twelve species (**Figure 28**). Yellow-faced Honeyeaters were again found to be common. This study compared bird populations in multiple sites in four categories one year after severe bushfire: stands that that had escaped burning; those that had burned but retained green canopy; those that had burned more severely (no green canopy); and those that had been salvage-logged after burning. Total bird abundance in burnt forest was about 60% of levels in unburnt forest, and salvage logging had reduced those to 9% of levels in unburnt forest. Nectarivores, canopy-foraging insectivores and bark-foraging insectivores remained common in burnt forest with green canopy, but had been reduced to about 40% in more severely burnt forest, and 0-10% after salvage logging[24]. Shrub-foraging insectivores and generalist insectivores had been more severely impacted by fire regardless of canopy condition. Open-ground insectivores were more common in severely burnt forest than in the other categories.



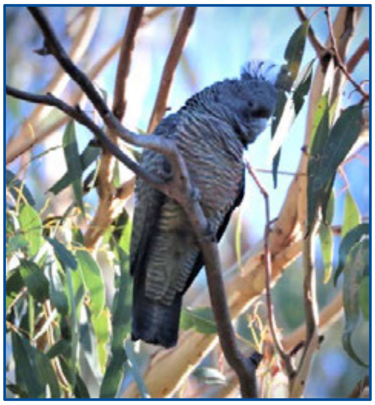

Figure 28. Three more bird species found in Alpine Ash forest in Victoria: **(left to right)** Crimson Rosella, White-throated Treecreeper, and Gang-gang Cockatoo (female pictured here). The Gang-gang Cockatoo is now listed as vulnerable (images: Richard Loyn).

Hollow-dependent bird species tend to be more influenced by forest age than forest type, and they were found to form a higher proportion of the bird community in mature Alpine Ash (16.7%) than in Mountain Ash of varying age (7.6%) (**Table 4**; Loyn 1985). The difference was especially marked for small hollow-dependent species, with Striated Pardalote being the most common: in Mountain Ash that species and Tree Martins are strongly associated with old forest stands in the breeding season (Loyn & Kennedy 2009). Treecreepers were generally less common in Ash forests than in mixed species forests (as they prefer rough bark for foraging), but two species are widely distributed both in Alpine Ash and Mountain Ash, with White-throated Treecreeper being substantially more common than Red-browed Treecreeper, and the latter mainly confined to mature stands. Treecreepers depend on hollows not only for nesting but also for roosting at night: this is unusual among Australian hollow-dependent birds. Two

[24] The study did not continue tracking the recovery of bird populations in the regenerating forest after salvage harvesting. A level of recovery is expected given other post-timber harvesting studies (e.g. Loyn 1993).

nocturnal species also need hollows both for nesting and roosting (Australian Owlet-nightjar and Sooty Owl), and some other owls use hollows for roosting on an occasional basis (e.g. Southern Boobook). All these nocturnal birds have been recorded both in Alpine Ash and Mountain Ash, with Australian Owlet-nightjars and Sooty Owls favouring gullies containing old trees and stands of cool temperate rainforest.

Table 4. Bird guild by nesting site, with selected bird species in Alpine Ash forests compared with Mountain Ash forests (from Loyn 1985). Data represent individual birds as a % of total bird community. Alpine Ash data is from East Kiewa, originally from Loyn & Woinarski (unpubl. 1980/90s).

Guild	Mountain Ash	Alpine Ash	Bird species
Nesting sites	**Various ages (% of birds)**	**Mature (% of birds)**	**Examples in Alpine Ash**
Small hollows in trees	4.1	**12.2**	Treecreepers; Striated Pardalote; owlet-nightjar
Large hollows in trees	3.5	4.5	Parrots; Cockatoos; Laughing Kookaburra; Owls
All hollows	7.6	**16.7**	All above
Burrows in the ground	3.6	**11.0**	Spotted Pardalote
Other, usually constructed nests.	88.8	72.3	Most birds

Most of the birds found in Mountain Ash forests are expected to occur in Alpine Ash forests to some extent, especially in gullies and other stands with suitable shrub structures. For example, Pilotbirds are widespread in areas with dense understorey; Crescent Honeyeaters, White-eared Honeyeaters and Olive Whistlers are common in stands of tall shrubs or dense regrowth; Large-billed Scrubwrens feed from branches of tall shrubs or suspended bark in mature eucalypts, and Pink Robins breed mainly in gullies with patches of cool temperate rainforest. Superb Lyrebirds (**Figure 29**) and Bassian Thrushes are most common where there is damp open ground below or in-between shrub cover.

Records from the State government's Biodiversity Atlas (DEECA 2023) show that approximately 110 bird species have been recorded in areas containing Alpine Ash forests, but some of these records may have come from associated habitats including other forest types, cleared land or wetlands. Specific studies of ash forests show that approximately 70 bird species are regular inhabitants of Ash forests (Loyn 1985; Lindenmayer 2009), albeit in varying proportions as discussed above. No species is confined to Ash forests: some are widespread across a broad range of forest types and others are confined mainly to wet forest types. The latter species tend to be slightly more common in Mountain Ash than Alpine Ash. No species is even confined to montane forests but a few species have high proportions of their breeding populations in forest at high elevations, such as Alpine Ash, with the Flame Robin and Pink Robin being the main examples. Several other bird species have significant breeding populations in montane forests but also breed in a range of forest types including heathy forests near the coast: examples include Gang-gang Cockatoo, Pilotbird, Olive

Whistler and Crescent Honeyeater (Emison *et al.* 1987). The upland population of Pilotbirds is classified as a distinct subspecies (Schodde & Mason 1999), though the boundaries between the upland and lowland forms are not clear.

Figure 29. The Superb Lyrebird, a male of which is pictured here at left displaying on a decaying branch in a Mountain Ash forest, also frequents Alpine Ash forests throughout the Victorian Alps, although generally in lower abundance.

(Image: Alex Maisey).

Gang-gang Cockatoos and Pilotbirds have recently been listed as Vulnerable nationally (Garnett & Baker 2021), with specific action plans in that document (Cameron *et al.* 2021 and Loyn *et al.* 2021 respectively).

3.1.4 Hollow-dependent mammals and their habitat

There are a range of hollow-dependent arboreal mammals, including possums and gliders, which occupy Alpine Ash forests, although the evidence indicates lower rates of abundance compared to other forest types. For example, in the Central Highlands, Leadbeater's Possum occurs in both Ash-type forests; however, only approximately 25% of their detections have occurred in the Alpine Ash forests of that region, as recorded in the Victorian Biodiversity Atlas (VBA; DEECA 2023). However, surprising detections can occur, such as that made by VicForests in 2017 on Connors Plains (M. Ryan *pers. comm.*), outside the official range of Leadbeaters Possum at the time (**Figure 30**; McBride *et al.* 2020).

The Greater Glider is uncommon in Alpine Ash, with past detections by VicForests' occurring only at the fringes with Mountain Ash (M. Ryan *pers. comm.*). The VBA supports this, with only 5% of detections occurring in Alpine Ash within the Central Highlands region. In north-eastern Victoria, surveys of arboreal mammals across different native forests revealed that Alpine Ash[25] was least likely to be occupied by arboreal mammals relative to the other forest types surveyed (Bennett *et al.* 1991). A similar study on the south-western slopes of New South Wales (Kavanagh and Stanton 1998) also found that species diversity and abundance was poorest at the driest and wettest extremities of an elevational gradient.

Therefore, in general, Alpine Ash forests had the lowest abundance of arboreal mammals relative to snow gum, peppermint, stringybark, and box forests types. The most frequently observed arboreal mammal in Alpine Ash forests in the Victorian Alps of north-east Victoria and south-west NSW was the Mountain Brush-tail Possum (**Figure 30**). This was followed by the Narrow-toed Feather-tail Glider (**Figure 31**) and the Greater Glider (Bennett *et al.* 1991; Kavanagh & Stanton 1998; Macak *et al.* 2010).

[25] Alongside River Red Gum forests

The Ringtail possum and Kreft's Glider (**Figure 31**) are also commonly observed in Alpine Ash forests (M. Ryan *pers. comm.*). Kavanagh and Stanton (1998) noted that none of the species detected across the range of forest types they surveyed appeared to prefer Alpine Ash forest over other forest types.

Figure 30. Two arboreal mammal species located by VicForests in Alpine Ash forest. **(Left)** A Leadbeaters Possum found on Connors Plains in 2017, and (middle) the tell-tale key-hole entry for this Leadbeaters Possum on the side of a fire-killed Alpine Ash.

(Right) A Mountain Brushtail Possum photographed in Alpine Ash forest during 2022 (images: Ben Drouyn and Mike Ryan, formerly VicForests).

Given that possums and gliders generally prefer higher elevation, wetter forests (Wagner *et al.* 2020), and that Alpine Ash is a preferential species for folivores owing to its high canopy foliar nitrogen (Wagner *et al.*, 2021), the reason why arboreal mammals are lower in abundance in Alpine Ash forests is not clear, but there are a few contrasting explanations. For example, in the Central Highlands the abundance of Mountain Brush-tail Possum is negatively related to the number of shrubs, excluding Acacia species, where more possum individuals are found on sites with fewer, non-Acacia shrubs (Lindenmayer *et al.* 1990). This may reflect the reliance of this species on Acacia for forage, which is also important for other arboreal mammals (Trouvé *et al.* 2019). However, given that some Alpine Ash forests can have a range of Acacia species present in the understorey, it does not explain the lower abundances of arboreal mammals detected in this forest type.

Another explanation may relate to the dynamics of habitat and hollow bearing trees with sufficient sized hollows to provide nesting or denning features in Alpine Ash forests. Kavanagh & Stanton (1998) observed that Alpine Ash sites with few arboreal mammal species also had few or no habitat trees present. The Mountain Brush-tail Possum, for example, typically requires short, large diameter trees with few holes for nesting (Lindenmayer 1997). The paucity of habitat trees in Alpine Ash forests may relate to the disturbance history of the specific sites in the Kavanagh & Stanton (1998) study, where historical timber harvesting or fire may have eliminated suitable trees. However, there may also be intrinsic factors associated with Alpine Ash forests which lead to lower abundances of hollow-bearing trees.

Figure 31. (Left) A Feather-tailed Glider feeding in Silver Wattle under Alpine Ash on Connors Plains, and **(right)** a Kreft's Glider (the newly renamed Victorian species of 'Sugar Glider') was commonly found by VicForests in Alpine Ash forests (images: Ben Drouyn and Mike Ryan, formerly VicForests).

Long-term studies geographically limited to the Central Highlands have found that hollow-bearing trees are generally lower in Alpine Ash forests compared to Shining Gum and Mountain Ash forests (Lindenmayer *et al.* 1991) and that there are fewer stem fissures in Alpine Ash than Mountain Ash (Lindenmayer *et al.* 1993). More recent studies in the Victorian alps have also indicated that abundances of hollows across a range of fire frequencies was generally low (Wagner & Nitschke 2021). Fox *et. al.* (2008) hypothesised that Alpine Ash grows at a slower rate than Mountain Ash, and therefore Alpine Ash forests would take a longer time to reach the larger size cohorts at which hollows begin to develop. However, this may be offset by the fact that hollows tend to develop in smaller Alpine Ash trees relative to Mountain Ash. About 75% of Alpine Ash trees greater than 136cm DBHOB had hollows, whereas Mountain Ash trees had to be larger than 160cm DBHOB to reach a similar proportion of hollow presence (Fox *et. al.* 2008).

Relative to other forest types, hollow abundance is consistently low in both Alpine Ash and Mountain Ash forests. Hollows in either of these forest types are influenced by the presence of non-ash eucalypt species in the overstorey mix, such as Manna Gum (*Eucalyptus viminalis*) or Mountain Grey Gum (*E. cypellocarpa*), which typically survive fire, develop fire scars and defects which lead to hollow development (Taylor & Haseler 1993; Adkins 2006; Fox *et al.* 2009). At least for arboreal mammals, this suggests that hollow abundance, and therefore habitat value, may be higher in mixed Alpine Ash stands compared to pure stands.

3.1.5 Nutrient cycling

Seasonal nutrient cycling in Alpine Ash follows similar pathways to Mountain Ash, such as via litterfall and associated decomposition into soils. Although colder conditions in Alpine Ash forests may slow the rate of decomposition (Attiwill & Leeper 1987), a study started in 1987 indicates that decomposition of litter is likely to be enhanced by ground dwelling fauna such as Lyrebirds (Ashton & Bassett 1997; **Box 2**).

Mineralisation of nitrogen in Alpine Ash forests is generally highest during summer months and lowest during winter; the low temperatures typical of this forest-type during winter can act to inhibit nitrification (Adams and Attiwill 1986). Just as fire plays an important role in the development and maintenance of Victoria's forest types, so too nutrient cycling in Alpine Ash forests is influenced by the dynamics of fire. Fire changes the chemistry of soil nutrient cycling through the deposition of oxidized organic matter onto the soil surface, by the direct effect of heat on the soil, and by the temporary cessation of uptake by the plants which are killed by the fire (Attiwill *et. al.* 1996). It is generally expected that following high-severity periodic disturbance by fire, key nutrients such as nitrogen and phosphorus may be immediately volatized, but the Ash-type forest is generally resilient to such disturbances with mechanisms that buffer against losses and assist in recovery. For example, rapid regeneration, higher growth and nutrient uptake following fire will reduce leaching from soils, the ever-greenness of eucalypts, and symbiotic nitrogen fixing such as by rapidly recovering Acacia species and quicker formation of associated mycorrhiza (Attiwill & Leeper 1987).

Box 2. Lyrebirds and nutrient cycling

The male Superb Lyrebird is strongly territorial and prefers higher slope positions for mound building, from which their song can carry during courtship displays. The night-time roosting trees of both male and female tend also to be upslope, and after gliding downslope from their roost trees, an upward slope movement generally occurs while feeding. Territories occur in Alpine Ash throughout Victoria, but could be larger than territories in Mountain Ash due to lower rates of productivity. During their daily up-slope trek, the bird's feed in open spaces clear of ground-ferns, displacing soil and litter downslope (**Figure 32**), contributing to nutrient cycling and shaping the micro-topographical profile of mountain slopes (Ashton & Bassett 1997; Bassett 2001; Maisey *et al.* 2020). Other micro-fauna contribute to nutrient cycling in much the same way as in Mountain Ash forests (Flint & Fagg 2007).

Figure 32. A female Superb Lyrebird feeding in soil under mixed eucalypt forest, East Gippsland. Note the powerful feet turning over litter.

The frequency of disturbance, however, can alter nutrient cycling patterns in Alpine Ash forests. For example, after low-intensity (prescribed) fire in high elevation mixed forests which contain Alpine Ash, it takes approximately 12 years for replacement via natural inputs of the nitrogen stored in litter and understorey (Raison *et al.* 1985). In the case of phosphorus, it may take in excess of 20 years for the replacement in litter and understorey shrubs, though the effect of fire may cause an immediate elevation of phosphorus in the fine ash generated by the fire (Raison *et. al.* 1985). Given the importance of longer fire intervals in recovery of nutrients, frequent fire may therefore result in a general reduction in availability of nutrients in impacted stands.

3.2 Ecosystem dynamics and disturbances

3.2.1 Influence of fire

Fire is one of the fundamental factors driving the dynamics of regeneration and succession in Alpine Ash forests. Alpine Ash is thin-barked and without strong resprouting capacity (Waters *et al.* 2010) (see **Box 3** and **Section 3.1.2**) and is classified as an 'obligate seeder'. Obligate seeders are species in which the mature individuals are killed by bushfire of moderate to high intensity, and population recovery depends on the success of seed dispersal and germination of seeds after falling from the canopy or, if present, a soil seedbank (Whelan 1995). However, Alpine Ash generally lacks a soil seedbank and is characterised by a high dependence on the canopy stored seed that is available at the time of the fire to adequately regenerate. The species can hold seed in soil for two seasons, especially where a secondary dormancy (see **Section 4.3**) has inhibited germination in the first season, leading to protracted recruitment (Bassett *et al.* 2012); but this is usually only a small proportion of original seed fall. Alpine Ash is one of nine obligate seeder eucalypt species which occur on the east coast of mainland Australia (Nicolle 2024), and this regeneration strategy contrasts with the majority of eucalypts in Australia, of which mature individuals are capable of both resprouting and seeding post-fire (Gill 1997; Nicolle 2024).

It's worth reiterating that Alpine Ash is not strictly a 'serotinous' species[26]. Like most eucalypts, Alpine Ash will naturally release seed from its canopy in the absence of fire, with a peak usually in late summer into autumn (Grose 1960b, 1963). Fire does induce an immediate and pulsed release of seed compared with seasonal dissemination (Grose 1963; O'Dowd & Gill 1984) (see also **Chapter 4**). As such, when severe fire fully combusts or scorches the Alpine Ash canopy and the mature adult trees are killed, a pulse of seedfall from the scorched or consumed canopy is released (as many as 4,000 seeds/m^2; O'Dowd and Gill 1984). This germinates on the ash-bed which has been cleared of competing vegetation and is rich in nutrients, leading to the development of an even-aged stand (Jacobs 1955; Cunningham 1960; Ashton 1976; O'Dowd & Gill 1984; Vivian *et. al.* 2008). The density and pattern of seedling regeneration can vary widely at the stand scale, with patches of highly dense seedlings occurring where optimal regeneration niches exist (Battaglia and Reid 1993a; Trouvé *et al.* 2021a) (**Figure 33**). Dense regeneration rapidly thins – for example, following the 2013 Harrietville-Alpine bushfire in Alpine Ash forest, an average of 500,000 seedlings/ha germinated under fire-killed mature canopies, then dropped to 308,000 seedlings/ha after 6 months (Bassett *et al.* 2015) (see also **Section 1.2**).

The above model of stand-replacement and even-age regeneration depends on the assumption of the fire being severe and the death of the mature Alpine Ash stand. However, variation can occur in a range of factors, such as fire severity and stand level attributes, which can lead to more variable outcomes. For example, within the boundary of a fire, variation of fire severity and topography can lead to dispersed pockets of Alpine Ash which may be burned lightly by low or moderate severity fire and, as such

[26] Serotiny, or more specifically, *pyriscence*, refers to plants that require heat or combustion to stimulate the release of seeds from the canopy.

Box 3. Resprouting Alpine Ash – the view from Tasmania

Generally, even after severe fire, Alpine Ash in Tasmania is a more reliable survivor and resprouter, whereas the Victorian mainland subspecies usually dies and is an 'obligate seeder' (**Figure 34**). This confers greater survivorship to mature trees after high severity fire in Tasmania, with about 36% of Alpine Ash trees surviving compared to 1% in mainland forests (Vivian *et. al.* 2008; Bowman *et. al.* 2014; Rodriguez-Cubillo *et. al.* 2020).

Figure 34. The contrasting vegetative response of Alpine Ash to high severity fire after 12 months: **(left)** mainland, and **(right)** Tasmanian subspecies (right image: D. Bowman).

The resprouting feature in Tasmania has been noted by foresters for some time and is a factor considered in the development of uneven-age silvicultural systems for the species (Neyland & Cunningham 2004; Neyland 2010). Differences in recovery strategies during the development of adaptation capacities may possibly be due to differences in fire frequency, but this remains unresolved (Rodriguez-Cubillo *et. al.* 2020). While greater survivorship of mature trees means that immaturity risk is reduced, it remains unclear how well-adapted Tasmanian Alpine Ash is to increased frequency of severe fires. For example, seedlings and saplings of the Tasmanian subspecies do not basally resprout nor fully develop epicormic resprouting capacity until mature, meaning that local population collapse may still occur where immature trees dominate (Rodriguez-Cubillo *et. al.* 2020). Given this, any consideration of the use of the resprouting Tasmanian subspecies for reforestation on the mainland[27] entails much uncertainty, and would require significant amounts of additional research, as well as revision of policy and regulatory barriers.

[27] As discussed in current climate change adaptation approaches (for example, Lavorel *et al.* 2015; Colloff *et al.* 2016).

are not fire-killed (Ashton & Attiwill, 1994; Simkin & Baker, 2008). It is also possible that individuals with slightly thicker bark may provide additional protection from fire, as has been suggested for Mountain Ash (Ashton, 1981). Multi-age stand structures may develop where seedlings opportunistically germinate amongst a partial surviving overstorey (Grose 1957 cited in Adams *et al.* 2013). However, the long-term survival prospects of seedlings which germinate under a live canopy is low: nearly 99% of Alpine Ash seedlings that germinate after low severity fire die in the first decade, leaving 1 to 2 surviving saplings per hectare (Gale & Cary 2021). Live overstorey eucalypts are known to suppress seedling regeneration under their canopy (Bassett & White 2001). From 10 to 40% of Mountain Ash stands have been estimated to have multi-aged cohorts, depending on the scale and method of assessment (McCarthy & Lindenmayer 1998; Walshe 2001). Similar assessments have not been made in Alpine Ash forests, but observations suggest perhaps less than 10%. Even the weak epicormic resprouting capacity of Mountain Ash (Waters *et al.* 2010) means that resprouting after low-moderate severity fire is possible, leading to the development of multi-age structures (Trouvé *et al.* 2021b). Although this capacity in mainland Alpine Ash has not been extensively investigated, long-term observations by Victorian silviculture foresters indicate that it is possible (**Figure 23**) <u>but rare</u> (see **Box 3**).

Figure 33. A dense patch of Alpine Ash seedlings following the 2003 bushfire, indicating mass seed fall from a fire-killed mature stand in the headwaters of Wheelers Creek, Hume Region.

(Image: Caitlin Cruikshank).

After high severity fire and regeneration, Alpine Ash seedlings do not reliably produce their own seed until approximately 20 years of age (Bassett 2011; Fagg *et. al.* 2013) (see **Chapter 4**). This period is known as the 'primary juvenile period' (Keith 1996) and when fires re-occur within this interval, Alpine Ash is unable to naturally regenerate and can become locally extinct[28] (**Figure 35**) (Bassett *et al.* 2015; Bassett *et al.* 2021). One study in Alpine Ash forests found that a second fire within 4 years killed 97% of regenerating stems (Bowman *et al.* 2014). Another in 2013 showed little or no Ash regeneration in areas where natural seed supply was predicted to be absent (Bassett *et. al.* 2015).

[28] Known also as 'extirpation'.

Given the poor seed dispersal capacity of eucalypts (Potts 1990; Florence 1996), the prospects are low for these areas being recolonised via seed from outside the fire footprint, and these areas are likely to transition to understorey dominated by species such as *Acacia* and/or *Daviesia*. High elevation sites can transition to snow grass, perhaps with a remnant of fire-resilient eucalypts, such as Mountain Gum (Costermans 2009; Bassett *et al.* 2012; Bassett *et al.* 2021; also see **Box 14** in **Chapter 7**). 'Immature fire killed Ash regeneration' (IFKAR) is a significant challenge for forest managers (Grose 1960b; Needham 1960; Moulds 1991; Ferguson 2011; Fagg *et. al.* 2013; Bowman *et al.* 2014; Bassett *et al.* 2015; Enright *et al.* 2015; Fairman *et al.* 2016; also see **Box 4**), exacerbated by the rapid accumulation of fuel in young forests (20 t ha^{-1} in 15 years after fire; Raison *et al.* 1983) and the risks of changing fire regimes under climate change (McColl-Gausden *et. al.* 2021). The management and recovery of forests impacted by short-interval bushfires is covered in **Chapter 7**.

Figure 35. Alpine Ash forests impacted by short-interval bushfires. **(Top)** Airborne, regenerating Alpine Ash near Sassafras Gap, Corryong being burnt by high intensity fire, January 2020 (David Brown, CFA). **(Lower right)** Alpine Ash forest burnt by two short-interval fires near Mt Useful, Gippsland. Note the white stems of mature Ash killed 2007, then burnt again 2013. **(Lower left)**: Ground view from the Dargo High Plains Rd of Alpine Ash burned by three severe fires (2003, 2007, 2013) in the Alpine National Park. Note the second fire has killed the regrowth before seed bearing age, leaving no capacity for natural recovery. (Lower images: Tom Fairman, taken 2022).

Box 4. Alpine Ash forests, forest age and fire severity: the state of the science

Following extensive bushfires in south-eastern Australia over the past two decades, a range of conceptual models have been developed to 'explain' the factors leading to such large, severe and frequent fires. The expected impacts of climate change on forest fires has also heightened the need to understand the drivers behind short-interval bushfires in Ash forests, especially given their value (Keenan & Nitschke 2016). Two high-profile concepts which seek to do this are the 'landscape trap' (Lindenmayer *et. al.* 2011) and the 'interval squeeze' models (Enright *et. al.* 2015). The 'landscape trap' model hypothesises that 'intrinsic' stand-level factors like fuel load and forest structural characteristics elevate the likelihood of Ash forests burning and re-burning. This model focusses on timber harvesting as a major driver of landscape scale fire patterns. The 'interval squeeze' considers plant ecology, such as the time to reproductive age, and emphasises 'extrinsic' factors like fire weather and climate being the key factors which risk the viability of Ash forests under future bushfires. This latter model is also supported by Ferguson & Cheney (2011).

These conceptual frameworks have generated intense interest and research, particularly where it relates to the role of timber harvesting in influencing subsequent fire severity. A number of subsequent papers have suggested timber harvesting: elevates fire severity (Taylor *et. al.* 2014; Lindenmayer *et. al.* 2020, 2022); has no bearing on it (Attiwill 2014; Bowman *et al.* 2021; Keenan *et al.* 2021); is inconsequential when considering landscape patterns of fire severity during major bushfire events (Bowman *et al.* 2022); or that any detected influence is subordinate to broader patterns of climate and fire weather (Bowman *et al.* 2016).

Each of these papers, however, have their limitations. Many rely on remote sensed data of fire severity, which has its limitations when analysed across different forest structures. For example, at a given fire intensity, young forests may have their canopies fully scorched due to the crown being lower to the ground (Gale & Cary, 2022) - a fire of the same intensity in a mature forest may only partially scorch the canopy given the greater distance between the canopy and the fire (Burrows, 1994). Field based evaluation of the post-disturbance fuel dynamics that underpin the competing theories found limited evidence for many of them (Cawson *et al.* 2018), reiterating that fuel loads in Ash forests can be relatively high irrespective of forest age, and that fire occurrence is not so governed by fuel abundance, but rather its availability to burn. Nonetheless, extensive fire suppression programs, particularly under benign weather conditions (FFMVic 2022), may have the unintended consequence of elevating fuel loads across the landscape and providing fuels for future uncontrollable fires. These complex and interacting factors mean that managing Ash forests under an increasingly dry future will pose serious fire management challenges which transcend historical land-use debates relating to timber harvesting.

It is worth noting that the above timelines relating to primary juvenile period and immaturity are general 'rules-of-thumb' developed to broadly guide forest management decisions, and there are exceptions. As explored in **Chapter 4**, flowering and seed production in Alpine Ash is not solely governed by time with aspects of tree physiology and structure also playing a role in seed maturation. For example, within dense regenerating Alpine Ash stands under fifteen years, suppressed individuals were observed to initiate flowering and development of seeds earlier than non-suppressed individuals (Gale & Cary 2021). In this case, it may be that these overtopped individuals redirect resources from latent height growth to flower and seed development. Viable seed has been collected from suppressed Alpine Ash individuals estimated to be 6-7 years old (Fielding 1956; Doherty *et al.* 2017), however no estimates have been made of the size of the seed crop at this early age. Assessment of 17 year old Alpine Ash stands following the 2020 Black Summer bushfires revealed a seed crop of average intensity 51,000 seeds/ha and high variability (Lutze & Bassett 2020), but note that this is as little as 0.1% of the seed crop of a mature stand (O'Dowd & Gill 1984) and was therefore not deemed adequate for forest recovery in 2020 (Bassett *et al.* 2021).

Variation in fire intensity means that even in frequently burned forests, for example - three severe fires between 1998 and 2019, it is possible that Alpine Ash individuals may survive and remain as an ongoing seed source to guarantee species persistence, albeit with a very variable stand structure (Wagner & Nitschke 2021). However, following frequent post-fire damage assessments by Forest Solutions in 2009, 2013, 2018, 2019 and 2020, it is clear that the proportion of surviving mature forest is reduced after each fire (Bassett *et al.* 2015; Bassett & Galey 2018, 2019; Bassett *et al.* 2021). At the rate of mature forest reduction of the last two decades in Victoria, one author (O. Bassett) predicts that all mature Ash could locally disappear inside recent fire footprints if burnt severely again. In fact, this has occurred already in some places at a landscape scale after only two fires, for example, in the Corryong district (**Figure 36**) and after three fires in the Licola district (**Figure 37**).

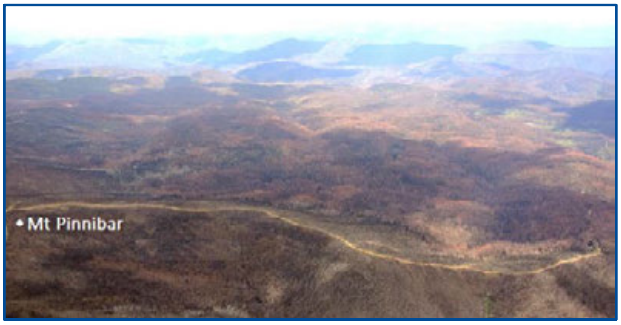

Figure 36. Airborne, looking NW across the Mt. Pinnibar access track towards Dunstans, showing an expanse of fire-killed Ash and other forest-types in the Pinnibar Pendergast State Forest damaged during 2020. Surviving mature Ash forest cannot be seen.

(Image: Bassett *et al.* 2021)

Figure 37. Airborne, looking north into the eastern sector of the Carey State Forest, from a flight-position just north of Lake Tali Karng. MacFarlane Road is in the vicinity. No mature Ash remains alive here post-2019, and all regrowth from either the 1998 or 2007 fires has been killed. Live mature Ash forest can be seen outside the 2019 fire boundary in the distance.

(Image: Bassett & Galey 2019)

Further research on the sufficiency of seed supply from suppressed or small numbers of surviving or precocious individuals in maintaining viable populations of Alpine Ash is required, particularly in the context of 'ecological stocking'. Otherwise, without artificially-applied seed to such IFKAR stands, as per Fagg *et al.* (2013), climate driven short-interval fires will remain a major risk to this forest type into the future.

3.2.2 Influence of windthrow

Severe windstorms can cause significant, usually localised, damage to the stands of both Mountain Ash and Alpine Ash (**Figure 38**), particularly where they occur on shallow soils, are on exposed, open slopes and when severe winds occur from unusual directions, including wind-shear events. In terms of analogues to anthropogenic disturbance, windthrow is similar to a clearfell harvest rather than bushfire, without the slash-burn component, as windthrow results in extensive damage and felling of overstorey trees, whereas severe bushfires leave standing live and dead trees on site (Lindenmayer & McCarthy 2002).

Figure 38. Windthrow in a 1939 regrowth Alpine Ash forest, Upper Thomson, Gippsland during 2016 (image: Quinton Pakan).

A useful and indicative windthrow case study in Alpine Ash is a severe windstorm that occurred in 1998 near Mt. Gelantipy in East Gippsland in which virtually all overstorey trees (995 in number) were uprooted across a four hectare patch (Florentine & Westbrooke 2004). Four years after the windthrow, establishment of Alpine Ash seedlings was considered low at 49 seedlings per hectare, with the area being colonised by light-demanding trees, such as Silver Wattle (*A. dealbata*) at 2,210 seedlings per hectare. Invasive species like Blackberry (*Rubus fruticosus spp. agg.*) were also present (Florentine & Westbrooke 2003, 2004). In windthrown areas such as these, the root-ball of uprooted trees can provide a substrate for regeneration, but one author (O. Bassett) followed the fate of such seedlings after two windthrow events; one at Beenak in Mountain Ash, and the other in Alpine Ash on the Blue Range, Rubicon State Forest, and found the top of root-balls to be an unstable substrate and too far away from the solid soil base for long-term root establishment. All seedlings perished after two years at both sites.

Such scenarios illustrate how severe windstorms do not create a widespread receptive seedbed for ash eucalypt regeneration, and in the absence of intervention or additional disturbance lead to significant long-term changes in stand structure and composition.

The Mt Gelantipy windthrown site mentioned above was burned five years after the event in the widespread Alpine fires of 2003. Following these fires, Alpine Ash seedling recruitment at windthrown sites was significantly higher compared with the abundances prior to fire; being 9,360 seedlings per hectare one year post-fire, decreasing to 5,720 seedlings per hectare two years after the fire (Florentine *et al.* 2008). Additionally, monitoring of sites which had been windthrown and burned, and sites which had only been burned, showed that seedling density was generally higher at sites which had been subject to both windthrow and fire, at 5,720 seedlings per hectare compared with fire alone at 1,457 seedlings per hectare (Florentine *et al.* 2008).

These results indicate that the bushfire generated a suitable seedbed by eliminating woody debris and undergrowth competition. Additionally, it appears that the uneven and disturbed soil surface produced by the uprooting of trees may have created a variety of microsites and shelter which is conducive to Alpine Ash germination (Grose, 1960b; Battaglia & Reid 1993a). Despite 99% of mature Alpine Ash being uprooted in the initial windstorm, sufficient seed was evidently released from nearby standing and burnt mature Alpine Ash approximately 50 m from the windthrow zone (Florentine *et al.* 2008).

These observations and studies show that, to ensure Alpine Ash establishment in areas subject to windthrow, post-windthrow burning and broadcast sowing is advisable, particularly if 'waiting for a bushfire' is not an option.

3.2.3 Influence of pests and diseases

Browsing by herbivores

A range of herbivores can impact Alpine Ash forests, and there is wide-variability in browsing pressure across in the landscape (Sebire 2002; Poynter & Fagg 2005; Di Stefano *et al.* 2009), but generally the threat of browsing is most acute for regenerating seedlings (Bulinski, 1999; Di Stefano *et al.* 2007). Eucalypts often appear in the diets of deer (Forsyth & Davis 2011; Davis *et al.* 2016) and swamp wallabies have been identified as a risk to commercially managed native forests (Sebire 2001; Di Stefano *et al.* 2009).

Swamp Wallabies prefer wet and dense vegetation for food and shelter, which is likely found in recovering forest following disturbance (Lunney & O'Connell 1988), though browsing pressure has been recorded in drier, open forest types (Di Stefano *et al.* 2009). The density of swamp wallabies in a patch of forest one year after timber harvesting was five times higher than undisturbed forest, though severe browsing damage impacted only 13% of 12 month old seedlings (Di Stefano *et al.* 2007). The impact of this rate of browsing to well-stocked stands is expected to have little effect on overall regeneration success.

In fact, browsing severity in Alpine Ash was found by Sebire (2002) to be lowest of all commercial forest types in Victoria, and did not factor as a significant issue for the forest type in two consecutive State regeneration performance reports (Bassett & White 2003; Fagg *et al.* 2008). Rather, herbivores may pose a greater risk to Alpine Ash regeneration where it is of lower density, or somehow otherwise compromised. This may be where regeneration has failed after the initial attempt post-harvest, causing second attempt regeneration to be more difficult (Bassett & White 2003; Di Stefano *et al.* 2009), or where eucalypt stocking density is depressed due to disturbance history. In Alpine Ash, this could be forests subjected to multiple severe fires. For example, in an area of native forest which had been destocked of eucalypts after successive fires, all eucalypt seedlings which were unfenced in a trial planting were completely consumed by herbivores within three years (Ashton & Chappill 1989). In these instances, any browsing pressure poses an elevated threat to the few surviving seedlings, which may be further elevated by rising populations of invasive herbivores such as deer.

Foliar damage by Phasmatids

Spur-legged Phasmatid (*Didymuria violescens*) (**Figure 39**) is a particularly well-known defoliator of ash-type forests, being responsible for substantial defoliation of Mountain Ash and Alpine Ash regrowth across the Central Highlands region and north-eastern Victoria (Newman & Endacott 1962; Smith *et al.* 2008; Turner *et al.* 2011; **Figure 40**). The Phasmatid generally has a biennial lifecycle and, as such, populations rarely peak in successive years, but rather have 'peaks' and 'troughs' (Flinn *et al.* 1984). Typically, the eggs of the insect hatch between spring and summer after incubating on the forest floor for about 20 months; the nymphs then proceed to climb nearby eucalypts to feed on as their primary source of food and water (Neumann *et al.* 1977; Turner *et al.* 2011). The nymphs and adults feed high in the eucalypt canopy, with immature leaves being eaten by both adults and nymphs, and mature leaves targeted only by adults.

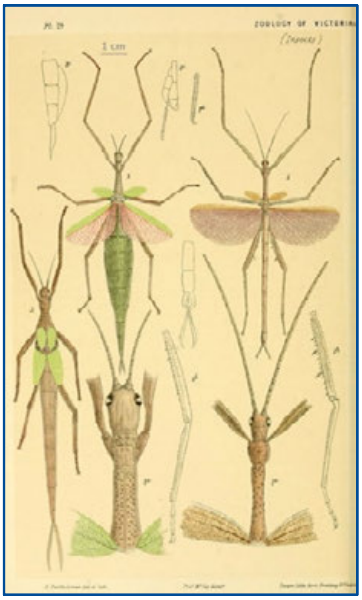

Figure 39. Phasmatid (a 'stick-insect') (Didymuria violescens): source Wikimedia Commons, from McCoy (1883).

Early outbreaks in NE Victoria caused concern for the State Electricity Commission, given it was thought that defoliation could lead to the death of Alpine Ash, damaging erosion, and impact water quality and supply to the Kiewa Hydro Electricity Scheme (SEC 1961). Assessment of insect life cycles to assess and predict outbreaks were undertaken, followed by aerial spraying of insecticide (Newman & Endacott 1962). In subsequent decades, the Forests Commission of Victoria and its predecessors undertook studies, assessments and treatments to protect future timber production (Neumann *et al.* 1977; FCV 1978[29]; Runnalls & McCormick 1981; I. Smith[30] *pers. comm.* 1996; Collett & McCormick 2001).

[29] Operational example, 800 ha Alpine Ash in the East and West Kiewa aerial sprayed for Phasmatid (FCV 1978).
[30] Centre for Forest Tree Technology memo to D. Buntine (Regional Manager): 5th December 1996.

Figure 40. Airborne: Phasmatid defoliation in Alpine Ash during aerial surveys of landscape-scale damage in 2001. (Image and line work: M. McCormick in Schoenborn *et al.* 2003).

Adults, particularly egg-laying females, are the most destructive (Flinn *et al.* 1984) and the species can have a very high reproductive potential - up to 300 eggs per female can be dropped between February and March onto forest litter, (Neumann *et al.* 1977), after which the lifecycle commences again. The species presence is a normal part of the ecology of eucalypt forests, but there are a range of factors hypothesised that can lead to outbreaks in Phasmatid population numbers. Neumann *et al.* (1977) observed that the first known outbreaks began to occur in approximately 20 year old even-age regrowth following the 1939 bushfires.

The factors thought to induce these outbreak include a combination of absence of disturbance and hence development of a well-structured litter bed, with canopy closure providing shade and increasing the moisture of the litter bed; all leading to optimal breeding sites and protection from predators. This suggests that dense, even-aged regrowth stands of Ash-type eucalypts are more likely to be at risk from Phasmatid outbreaks. Although Runnalls & McCormick (1981) did recommend treatment in small areas of mixed eucalypt forests in the Tallangatta districts, more widespread observations that large scale outbreaks have not been observed in mixed species forests, despite endemic populations of Phasmatid being recorded in these areas, seem to support this conclusion (Neumann *et al.* 1977).

Given the extensive area of ash-type forest impacted in the early 2000s, Phasmatid outbreaks may increase in prominence in the 2020s. An accurate prediction of Phasmatid population abundance can be achieved by sampling forest litter and counting both viable eggs and empty shells once hatching begins. Once hatched, the capture and analysis of Phasmatid frass falling from the canopy can also indicate the intensity of outbreak.

There are two control mechanisms that have been historically applied:

(1) the aerial application of the insecticide Malathion (Newman & Endacott 1962), undertaken when it is likely that the immature stages of the insect is present; being typically January to early February, contingent on elevation and seasonal climate. Malathion continued to be recommended until at least 1981 (Runnalls & McCormick 1981). It is likely that the use of insecticide is no longer acceptable in current forest management practice (Collett 2006).

(2) the application low intensity burning of litter in autumn, which aims to eliminate eggs in the litter layer before hatching (Neumann *et al.* 1977; Runnalls & McCormick 1981; Flinn *et al.* 1984).

Pinhole borers

The Pinhole Borer *Austroplatypus incompertus* has a number of host eucalypt species, including Alpine Ash (Kent 2010). Pinhole borers excavate tunnels at right angles to the grain in living trees, with sapwood and heartwood being penetrated by the gallery systems (Neumann & Harris 1974), though harvested green logs are thought to be most susceptible (Jenkin 2021). Alpine Ash, when attacked by pinhole borers, can develop large kino veins and gum pockets which can degrade timber values (Nicholas & Hay 1990).

Psyllids

The psyllid *Cardiaspina bilobata*, also known as the Mountain Ash Lerp (Collett 2001), feeds by sucking sap from the tissues of leaves and young plant shoots; severe infestations cause extensive foliage discolouration which can lead to leaf necrosis and defoliation. This can have serious implications for tree vigour, growth and survivorship when coupled with secondary infections of other pathogens (Collett 2001). Despite impacting Mountain Ash forest in the Central Highlands, at times substantially in the 1980s and 1990s, this species appears to not impact Alpine Ash forests.

Diseases

A wide range of diseases can impact eucalypts, and is the focus of the useful textbook by Keane *et al.* (2000). However, the book tends to focus on plantation eucalypts and is therefore has therefore less utility regarding disease in native forest Alpine Ash. Some good information on diseases in Alpine Ash, pest and disease were included in status reports prepared annually from 1990 to 2012 by the Native Forest Research Working Group No. 7, and provides useful context information (T. Wardlaw, *pers. comm.*). The following are some specific diseases relevant to Alpine Ash, including limited insights from the plantation sector.

Alpine Ash has been shown to be associated with *Phytophthora cinnamomi* (PC). Additional species of the *Phytophthora* genus have also been isolated in sub-alpine and alpine regions in southern-eastern Australia (Khaliq *et al.* 2019). However, the fungus may have little impact on Alpine Ash. For example, an East Gippsland study by Kassaby *et al.* (1977) clearly showed that PC inflicted no damage to Alpine Ash and Shining Gum located on the cool Errinundra Plateau (**Figure 41**). PC did not spread when patches of soil were artificially infected with it.

Figure 41. One author, P. Fagg, in the 1970s, undertaking soil measurements during research into Die-back disease associated with *Phytophthora cinnamomi* (FCV 1973).

In plantations of Alpine Ash in New Zealand, *Phytophthora fallax* has been associated with locally severe crown dieback outbreaks for multiple decades (Dick *et al.* 2006). Given that there are no native eucalypts in New Zealand, at the time of this research it was hypothesised that *P. fallax* exists in Australia. In the time since, *P. fallax* has been detected in south-eastern Australia, including in native forest environments, but has not been associated with any eucalypt dieback or disease outbreak events (Cunnington *et al.* 2010).

Some other diseases which may impact Alpine Ash include:

- Certain cankers (*Seiridium eucalypti*) (Old & Davison 2000);
- Infection of *Armillaria spp.* which includes the development of white mycelial sheets through the inner bark or roots and a white rot of sapwood amongst other symptoms, and has been reported in regrowth of Alpine Ash in Tasmania (Wardlaw 1996);
- Foliar fungal diseases are considered to be common in native forests, but rarely prove destructive and a major concern for forest management (Park *et al.* 2000). However leaf spot *Mycosphaerella delegatensis* appears as distinctive circular lesions five to 10 millimetres in diameter and has been observed on new-season growth of Alpine Ash and can lead to premature defoliation.

Box 5 provides some specific case studies regarding pests and diseases. Alpine Ash is also host to the following pathogens (Marks *et al.* 1982):

• Corky Leaf Spot (*Aulographina eucalypti*) • Grey Mould (*Botrytis cinerea*) • Weeping Polypore (*Grifola campyla*) • Austral Dryad's Saddle (*Neolentiporus maculatissimus*)	• Crinkle Leaf (*Mycosphaerella cryptica*) • Chalk Bracket Fungus (*Piptoporus cretaceus*) • Furry Punk (*Tyromyces pelliculosus*) • Ruby Bracket (*Tyromyces pulcherricmus*)

3.2.4 Influence of environmental weeds

There are numerous environmental weed species known to occur in Alpine Ash forests in Victoria. Most are more obvious as young plants following disturbances, but if Alpine Ash regeneration occurs successfully, then many of these, like Scotch Thistle (*Onopordum acanthium*) and other non-woody species, can become shaded-out following forest canopy closure. Although this can be considered a natural control mechanism, any seeds forming on these plants may spread and become soil-borne, only to then regenerate in larger numbers after the next site disturbance.

Weeds can contribute to the failure of eucalypt regeneration following bushfires and timber harvesting (Bassett & White 2003; Fagg & Bassett 2008; Bassett *et al.* 2012). They are rarely the primary cause, but invasion of weeds are likely wherever alpine eucalypt and understorey trees, like Alpine Ash and Mountain Hickory Wattle (*Acacia obliquinervia*), experience difficulty establishing. Weed invasion can tip the balance towards regeneration failure, given they reduce soil moisture and increase competition for space and other site resources. During drought, the impact of weeds on site establishment is magnified. Such weed presence can indicate a degraded site, difficult to regenerate, and often appear in conjunction with unnatural densities of native and introduced browsing animals like Deer, Rabbits and Wallaby (NRE 1999). Restoring such sites can require serious reforestation efforts (**Chapter 7; see also Box 6**).

Box 5. Case studies regarding outbreaks of pests and diseases in Alpine Ash

There are a number case studies of dieback or severe defoliation of Alpine Ash forest that highlight the range of potentially impacting pests and diseases that can afflict the species. In some cases, the symptoms of pest or disease are observed but no clear cause can be determined. In 2002, Chrysomelid Leaf Beetles (*Chrysophtharta agricola*) were observed to cause partial defoliation of regrowth Alpine Ash at the Nunniong Plateau in East Gippsland (P. Fagg, *pers. comm.* 2002) **(Figure 42)**. Defoliation from leaf insects such as these in native forests are generally related to variability in their population abundance, with outbreaks tending to be cyclical and occurring only for a relatively short-period before populations return to background levels (N. Collett, *pers. comm.* 2002). Causes of outbreaks are generally attributed to three factors: (1) prevailing climate conditions; (2) populations of predators; and (3) availability of suitable food resources. The general lifecycle for leaf insects in temperate regions begins in winter as either pupa or immature adults which shelter in vegetation or litter on the forest floor. In spring, adults then emerge and feed on expanding foliage. Eggs are laid on expanding leaves or shoots, and when they hatch, feeding continues throughout the tree crown during summer. Larvae then drop to the ground in early autumn where they remain as pupa or as immature adults. There may be more than one generation per year, depending on the species. It is possible that favourable climatic conditions, such as mild summers and winters, increase the number of generations per year and the probability of defoliation (N. Collett, *pers. comm.* 2002).

Other instances of defoliation have less clear causes. One such example occurred near Mt Wills in the north east of Victoria between 1995 and 1996. Here, defoliation of Alpine Ash occurred alongside the death of the understorey of hop scrub and was estimated to impact 200-300 ha of forest (Smith 1996). The drivers of this dieback were difficult to determine. There was no evidence of root pathogens, and while there was a presence of fungal diseases, psyllid and mite damage, none of these were clearly attributed to the dieback (Smith 1996). The Alpine Ash trees were observed to be resprouting and likely to recover (Ian Smith, *pers. comm.* 2022).

Figure 42. Thinned Alpine Ash at 36 year old on Nunniong Plateau, with partially defoliated crowns as photographed by Peter Fagg in the 1990s. The suspected cause was Chrysomelid Leaf Beetle.

The most prolific, persistent and dangerous woody weeds encountered in Alpine Ash forests are three 'Weeds of National Significance' (Weeds Australia 2024): Blackberry (*Rubus spp*.), Gorse (*Ulex europaeus*) and English Broom (*Cytisus scoparius*) (C. Paterson[31] *pers. comm.*). These species can persist under a forest canopy and, if left unchecked, will dominate sites at the ground level, with significant environmental impacts at the landscape scale.

Blackberry

Blackberry is a member of a large genus called *Rubus*, and although there are some native species, this Reference Manual is only interested in the group derived from the *Rubus fruticosus* aggregate (European Blackberry). At least 16 European species from this aggregate have been introduced into Australia, forming vigorous hybrids. These species were introduced during the 1830s, and have aggressively spread (DPI 2009). By 1894, the species was recognised as a noxious weed in Victoria and had spread to most parts by 1908 (DPI 2009). Blackberry's climatic range includes high elevations, and the species has well established into the Alpine Ash forest type (**Figure 43**). Large infestations can now be seen, overtaking riparian zones on creeks and rivers, lower gully slopes, and whole sections of mountain sides where moisture is readily available.

Blackberry is an aggressive reproducer, from both seed and vegetative sources, accounting for its successful spread.

Stems of Blackberry are known as 'canes', and the species produces primary (primocane) and secondary (floricane) canes that can be erect or trailing and which extend long distances, growing over structure to smother native ground vegetation (**Figure 43**).

Figure 43. A large thicket of Blackberry in Alpine Ash along the Blue Range east of Buxton in the Alexandra district. Image taken during the summer of 2023.

In this way, Blackberry can form huge elevated patches to 4 metres high or taller (**Box 6**). Where the tips of canes touch the ground, a new plant takes root, efficiently and aggressively spreading the species across the invaded site (DPI 2009).

Blackberry can impede regeneration operations in Victoria. Although it is rarely the cause of regeneration failure in Alpine Ash, its presence can contribute to it, and then later cause the site to be unproductive and difficult to recover in secondary or

[31] Manager of Mansfield & District Weeds Pty Ltd (Interviewed April 2024)

reforestation operations. **Box 6** is a case study of such a scenario, when recovery of an unregenerated timber harvesting coupe in NE Victoria had to include the first-step treatment of huge thickets of Blackberry.

Herbicide is the best treatment option in a forest environment, being the only option that would kill plants outright. Spot spraying is acceptable for small patches, but in the case of large patches within the landscape, machine mounted delivery with boom-spray configuration is required.

Spray units have been mounted on excavators to deliver herbicide during forest recovery operations (Sanders 2010; Bassett *et al.* 2012), but aerial application using a helicopter mounted boom-spray may be more efficient in mountainous country (**Box 6**). [32]Grazon® is currently the better herbicide option for woody weeds like Blackberry; used with a non-ionic wetting agent (C. Paterson, pers. comm. MAD Weeds). Grazon® acts on foliage and roots, and has a residual activity that prevents seeds and secondary weeds from germinating. Time after spraying is required to ensure death of the plant prior to further disturbance.

Gorse

Gorse (*Ulex europaeus*) is a European legume (pea) species (Fabaceae family) invading natural environments in Victoria, including disturbed forests (**Figure 44**). The species was introduced in the early 1800s and planted to create hedges and fodder for farm animals. Gorse is tough, tolerating a wide range of temperatures including those experienced in low to moderate elevation alpine regions, and once it flowers the resulting seed infects soil and is then difficult to eradicate from a site. *Best control occurs prior to its first flowering* (DAFF, Tasmania 2006).

Figure 44. Gorse in a soil-disturbed area of native forest in Victoria. The species can spread laterally to choke seedbed and prevent regeneration.

The main occurrence of Gorse in Alpine Ash in Victoria is in disturbed areas during regeneration and roading operations. Seeds may be spread by machinery. Fire encourages Gorse, and it will prevent native species from regenerating. It reduces floral diversity and, because of its high flammability, can alter fire behaviour when in large, high density patches.

An important feature of controlling Gorse is to commit to a long-term program of treatment and follow-up. Gorse requires an integrated approach in four general stages:

1. Prevent spread by washing-down machines, work-boots and work areas
2. Reduce above ground biomass of Gorse (herbicide or physical means)
3. Kill regrowth – both seedling and vegetative (herbicide), and
4. Follow-up treatment of seedling germination for at least 5 years (DAFF 2006).

[32] Active ingredients: 300 g/L triclopyr; 100 g/L picloram; 8 g/L aminopyralid

Box 6: A Case Study of treating Blackberry in an Alpine Ash forest

During 1985, an Alpine Ash coupe of 35 ha was harvested for sawlogs, with no pulpwood taken at the time given the lack of a market. This coupe is situated about 2 km from the Omeo Highway along the Razorback Spur near Mt Wills, NE Victoria. Efforts to regenerate the coupe following harvesting fell short of acceptable regeneration targets. Issues were the presence of overwood, given no pulpwood could be taken, and poor burns leading to sub-optimal seedbed condition. Blackberry quickly established and choked any established regeneration, covering 95% of the coupe area (**Figure 45** top image).

Government 'Greenhouse Funds' became available in 1999 for reforestation. An action plan to reforest the Razorback coupe was developed by the then Forest Planner (Ron Patterson), Forest Officer (Ernie Cole), Silviculture Officer (Owen Bassett) and Regional Manager, NE (Ross Runnalls). The treatment schedule included: aerial spraying 35 ha of Blackberry, waiting for full death, slash-burning, planting Alpine Ash seedlings, and then undertaking a spot-spray follow-up of surviving Blackberry. Paton Air (Dave Empy) provided the helicopter service, and the Blackberry was aerial sprayed using a boom-mounted helicopter on the 9th March 1999 (**Figure 45** middle), with slash-burning late April 1999 (**Figure 45** lower) and planting autumn 2000.

Figure 45. Razorback Blackberry treatment

(Top) Owen Bassett stands amongst thick Blackberry on the Razorback Spur during early inspections in 1999. Blackberry thickets reached 4 metres in height (see also Lower image).

(Middle) Boom-mounted helicopter unit.

(Lower) Owen standing beside a 4 m tall thicket of poisoned and burnt Blackberry, prior to planting.

(Images: Peter Fagg)

Broom

English Broom (*Cytisus scoparius*) is a native of Europe, and is a large shrub with deep yellow flowers (**Figure 46**). It is now established in Victoria and can enter Alpine Ash forested areas in similar fashion to Gorse. It is tough and tolerant of alpine and sub-alpine conditions, preferring cooler, higher rainfall regions. The species attracts pest animal species also, such as pigs and wild horses. Broom can become a secondary species invasion where species like Blackberry are removed (Weeds Australia 2024). In Victoria, it is abundant in the Mitta Mitta Valley and around Falls Creek.

Figure 46. English broom flowers during the October to January period.
(Image: Yarra Ranges Council website; 'noxious weeds', under 'environment').

Control is best using an integrated weed management program, including herbicide, physical removal and biological control (see Weeds Australia 2024).

4. Silvical Features of Alpine Ash

When managing Victoria's native Ash forests, the use of 'silviculture' is *the science and practice of regrowing forests following major disturbances, and of tending forests to achieve specific management outcomes*. Silviculture includes the development and supply of eucalypt seed and its germination, establishment of a developing regrowth forest, and forest growth into mature stages. The practice may also include tending, such as thinning to increase water yield, develop habitat sooner, recover structural integrity to damaged or changed forests, or increase resilience to drought and bushfire.

Fire can be used as an integral part of silviculture; to reduce fuels and increase the resilience of forests to bushfire using controlled burning, or create suitable seedbed conditions for seedling germination and establishment. Unintended damage can be inflicted, so knowing how a species responds to fire based on its silvical features is needed to manage this risk.

A 'silvical feature' therefore refers to a key life characteristic, natural response or life-cycle of a species that may influence the successful establishment, growth and health of the forest. For Alpine Ash these include the following:

- Seed biology; including budding, flowering, and seed development; see NFSG No. 1, 2nd edition (Bassett 2011)
- Seed maturation and dispersal
- Seed dormancy and cold stratification to break dormancy
- Seed germination
- Seedling survival and establishment
- Growth of seedlings into trees and forest development through to maturity, and
- Response to bushfire and the risk of population collapse.

4.1 Seed development

As for all eucalypt species, Alpine Ash seed develops following the fertilisation of ovules in flowers during the process of anthesis (Carr and Carr 1959; Grose 1960b; Bassett 2011). The process of seed development in this species, including anthesis, spans at least 4 years, beginning with the initiation of a solitary inflorescence bud in the axil of each new leaf (**Figures 47 & 48**).

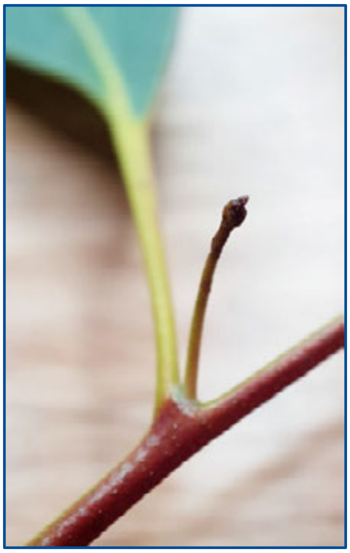

Figure 47. Inflorescence bud emerging from leaf axil. 2.5x magnification.

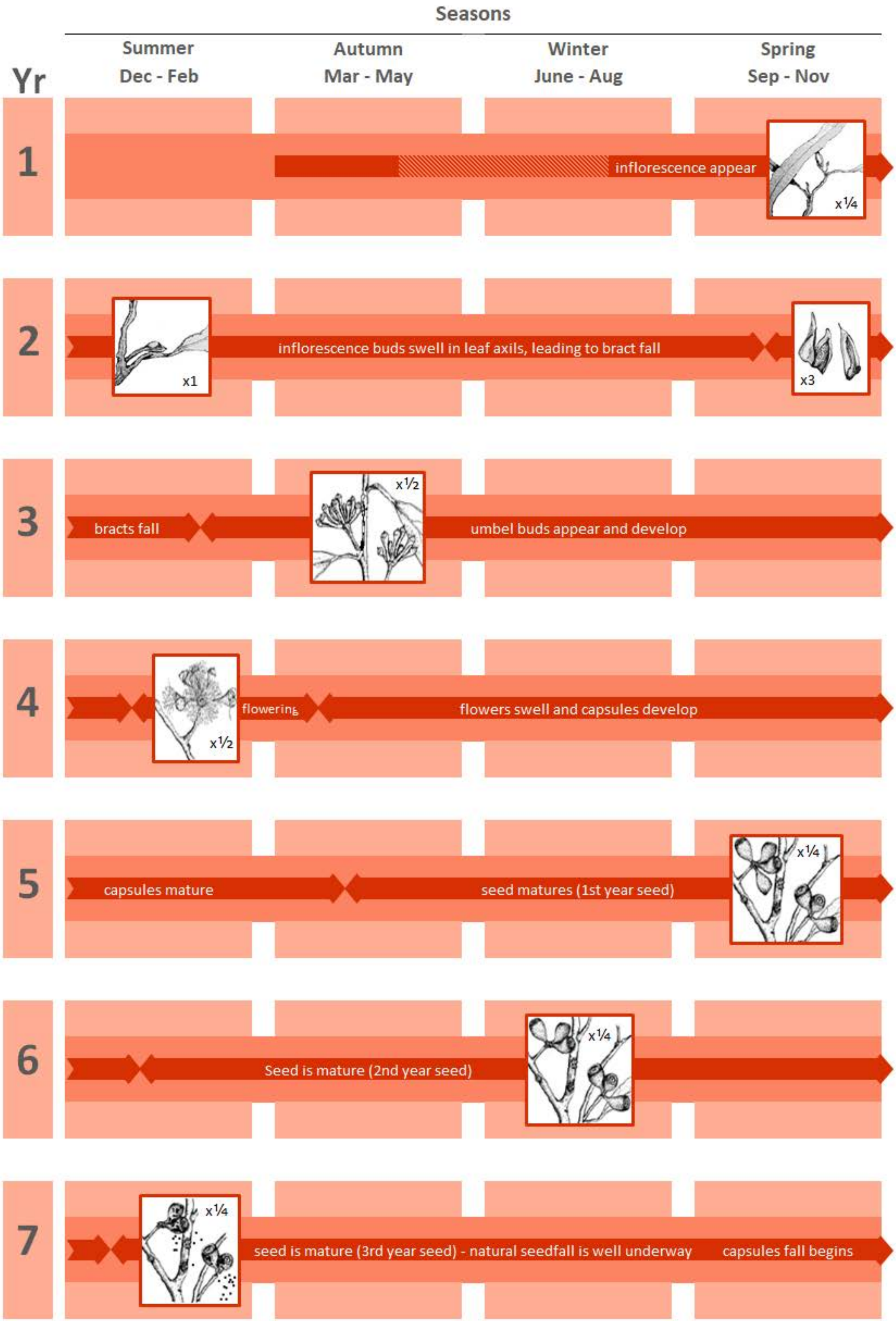

Figure 48. The sequence of seed crop development and maturation in *Eucalyptus delegatensis* (Alpine Ash) showing the development of an early-mature capsule crop (1st year seed) within 4 years.

4.1.1. Budding

Inflorescence buds appear in new tip growth during spring, but can continue to appear into the following autumn if seasonal conditions allow. This extended bud initiation occurred, for example, in the Victorian Alps during the growing season of 2021/22 (see **Box 7**).

Box 7. Extended bud initiation

During the autumn of 2022, inflorescence buds continued to appear as new leaves were being initiated beyond spring. Such summer and autumn new buds are considered late developers from the previous spring. Their fate is currently uncertain, but their expected long residence time over winter in their early, delicate stage of development may become a problem. This had not previously occurred in 20 years prior, given catchment soil moisture had not reached such high levels during that time, and so the study of extended bud initiation was not possible until 2022. If these late buds had survived winter 2022, the fall of bracts from them may also have extended into summer 2022/23 as the inflorescence eventually swelled. However, monitoring revealed that most umbellate buds produced during 2022 in this species were aborted, producing little flowering in 2023 (Bassett 2023).

Each inflorescence bud contains an umbel of umbellate buds enclosed by a whorl ('involucre') of six fused bracts (Carr & Carr 1959; Boland *et al.* 1980). As the enclosed umbellate buds swell, one or more tears appear in the involucre of bracts (see 'Figure 4b' **in** Boland *et al.* 1980), which is eventually ejected from the forest canopy as umbel buds grow and separate (**Figure 49**). Bract shed occurs 15 to 16 months after bud initiation, peaking during the months November and December.

Figure 49. Bract involucres (x4) shed from Alpine Ash, as a whole (at left) or, more commonly, as separate halves (the two on the right).

Observations made during long-term monitoring (**Box 8**) indicate that bracts can fall as whole involucres or, more commonly in Alpine Ash, as halves (see **Figure 49**), with one or two connecting fused bracts splitting entirely and separating. Note that Alpine Ash bracts falling as half involucres is a notable difference to Mountain Ash (*Eucalyptus regnans*), for which bracts usually remain fused and fall as a whole involucre. See NFSG No. 1 for floral morphology of that species (Bassett 2011).

The shed of bracts in Alpine Ash reveals simple umbels of 7-15 pedicellate umbellate buds. Each umbellate bud swells and elongates to take on a clavate appearance, and are capped with a hemispherical, apiculate operculum (**Figure 50**).

Figure 50. Umbellate buds of Alpine Ash sampled in March 2022 following their release from inflorescence buds during the previous December. Further swelling will occur. Magnification for the above image is about 4x.

At the beginning of anthesis, marked by the shedding of a flower cap ('operculum', see **Figure 52**), umbellate buds average 6.8 per umbel, with range 2-12 per umbel (see **Section 3.2**; also Bassett 2023), and are 13-14 months old, meaning that two bud crops can be present; one about to flower and a younger crop just released from their inflorescence.

4.1.2. Flowering

The first sign of anthesis, leading to flowering in Alpine Ash, is the tearing of an abscission layer formed at the base of each operculum on the umbellate bud. The line of eventual abscission is apparent even on young buds (**Figure 50**). As stamens unfold, the separating opercula is pushed away and falls to the forest floor. **Figure 51** shows operculum collected in floral traps during monitoring for seed forecasting (**Box 8** and **Section 4.2**). Alpine Ash flowers are made up entirely of cream-coloured stamens, each with a pollen-laden anther, unfolding from the centre of the nectary (**Figure 52 at right**) and exposing a single stigma via which fertilisation occurs.

Flowering period in Alpine Ash was first reported by Grose (1960b) to occur in January to March, about two years after the appearance of bud primordia. Boland *et al.* (2006) quotes 'December to March', being likely more indicative of the full range.

Flower and budding reports undertaken by the Forests Commission of Victoria (FCV) from 1960 to 1975 and which are based on flowering observations (custodian of 'FCV Form 336' data is M.R. Keatley) largely concur with Boland's range, indicating a trend in peak flowering towards February; with 'outliers' in November and May (**Figure 53**).

Bee keepers have long been acquainted with eucalypt flowering, reporting a November to April range for the species, with a January/February peak (Goodman 1973; Somerville 2019).

Box 8. Long-term floral monitoring of Alpine Ash

Studies of annual flowering and seed production based on floral component monitoring are numerous in eucalypt forests of southern Australia, but few span more than 3 years with limited capacity for temporal deduction (Rawal *et al.* 2015; Walsh *et al.* 2022). The longest published study is in Western Australia (11 years, Loneragan 1979). There are longer studies of flowering based on diarised floral observations made by Forests Commission Victoria (FCV); the most notable by Mr. Bill Sheen in Box-Ironbark forests during the period 1934-62 while Forest Overseer at Maryborough (Keatley 1999; Fagg & Bassett 2015). The FCV also monitored flowering in Alpine Ash using Flower and Budding Reports (see **Figure 53**).

To build on early knowledge of flowering and seed development in Ash species, undertaken by Grose (1957, 1960b) for Alpine Ash, and Ashton (1956; 1975) and Cremer (1972) for Mountain Ash, one author (O. Bassett) and colleague, the late Barry Roberts, began a long-term floral monitoring program in 1994 for the Victorian State government. Monitoring first began in Mountain Ash in 1994, with Alpine Ash added in 2002. Monitoring continues today by Forest Solutions Pty Ltd, now spanning 22 continuous years for Alpine Ash and 30 years for Mountain Ash. Monitoring is based on measurements of floral component production.

For Alpine Ash, 13 study sites across Central and NE Victoria were established to monitor the fall of bract involucres (**Figure 49**), operculum (**Figures 50 & 52**) and aborted flowers into 38 floral traps (**Figure 51**). Aerial flowering assessments are undertaken annually to map the spatial distribution of Ash flowering in Victoria. These data are used to forecast flower and seed crops up to 4 years in advance (**see Section 4.2**).

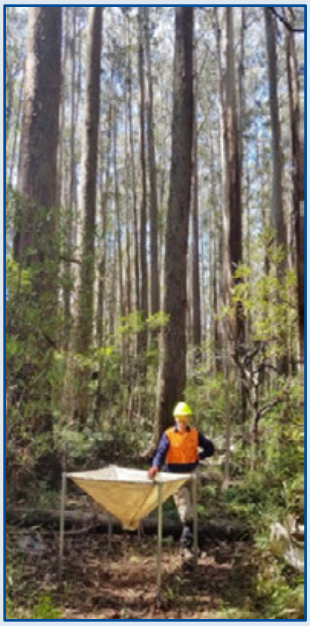

Figure 51. Forest Solutions staff: (Craig at left) a 1 m^2 floral trap under Alpine Ash in the Blue Range, Alexandra district; (Clancy above left) sieving trap contents to classify floral components into a fine fraction; (Jenny above right) identifying, separating, and sorting, counting and recording floral components from the fine fraction of one trap.

Figure 52. Opercula fall and flowering in Alpine Ash. **(Left)** fallen operculum (x4) collected at Quartz Creek on the Blue Range (Alexandra). **(Right)** flowers on Alpine Ash near Matlock, observed during floral monitoring in January 2018. Note the lifting opercula on umbel buds that are about to flower.

Recent long-term floral monitoring from 2002 to 2024 (ongoing), using the count of fallen operculum captured for seed forecasting (**Box 8; Section 3.2**), agrees with the timing of peak flowering for Alpine Ash during January or February, depending on season (**Figure 53 right**). During aerial flowering assessments for Mountain Ash, one author (O. Bassett) noted a band of high elevation Alpine Ash flowering in early May at Mt Baw Baw. Odd flowering outliers are rare but do occur, as seen in **Figure 53** for the August FCV 'data outlier'.

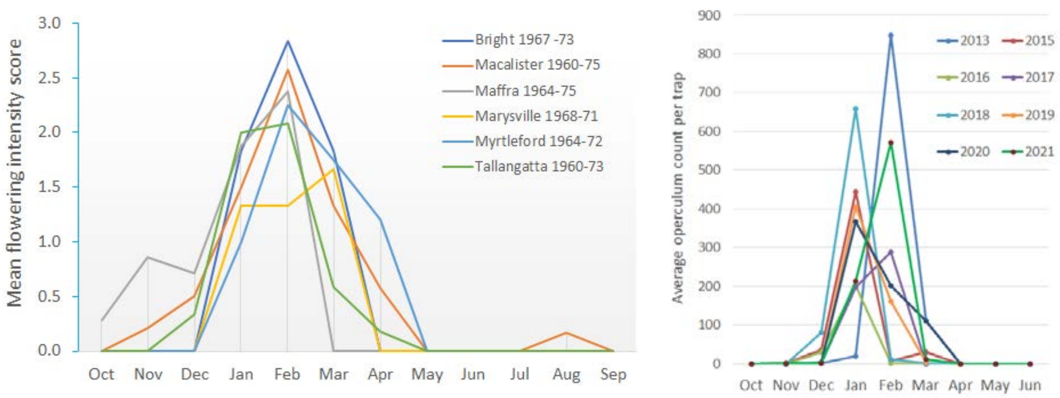

Figure 53. Two significant studies of Alpine Ash flowering showing the timing of peak flowering by month. **(Left)** data sourced from FCV budding and flower reports 1960-1975 (M. Keatley). **(Right)** Data from long term monitoring and seed forecasting 2002-2023 (Bassett 2023), based on Bassett (2011, **Box 8**). Only the recent heavier flowering years 2013-2021 are shown for clarity in the chart at right.

Given these recorded timings, the peak of flowering occurs up 25-27 months after the first appearance of inflorescence buds but can be longer. Grose (1960b) reports 24-25 months for Alpine Ash, but Fielding (1956) more closely concurs with the broader Victorian data set, observing up to 30 months for Alpine Ash in New South Wales.

Forest stands remain in flower for 3-4 weeks once operculum start to fall, with stamens falling after pollination (**Figure 54**). Nectivorous insects, such as hover flies and bees, are the predominant pollinators, with some species of honeyeaters and gliders also contributing (Griffin 1980; House 1997). Good synchronisation of flowering between trees within forest stands during heavy flowering ensures a high level of out-crossing (Griffin 1980; House 1997; Bassett 2002). As an example for Alpine Ash, Bassett (2021) recorded within-stand spatial coefficients of variation (CV) in flowering intensity of only 20-30%[33], with up to 70% of trees concurrently in heavy flower during peak flowering times (**Figure 54**).

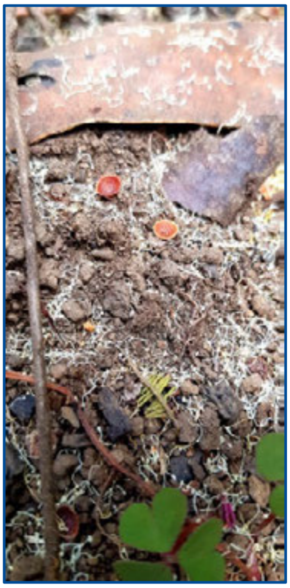

Figure 54. Airborne. Landscape-level flowering of Alpine Ash near Mt Phipps in the Swifts Creek District during January 2024 **(above)**, and **(right)** operculum and stamens litter the forest floor in the Rubicon State Forest following heavy flowering during 2021 (see also **Figure 66**).

Temporal variation of annual flowering intensity in mature Alpine Ash

Grose (1957; 1960b) acknowledges the tendency for Alpine Ash towards biennial flowering, with a light year usually following a heavy year; confirmed by Goodman (1973) and Bassett (2011) for the species, and likely due to the draw-down on starch reserves and the need for recovery following heavy flowering (D. H. Ashton *pers. comm.*). However, Grose reports that another heavy year of flowering in the cycle is by no means guaranteed, with bud or flowering crops failing for numerous reasons. For example, three light flowering years followed a heavy year in 1954 during his study.

[33] A coefficient of variation (CV) of less than 50% in natural systems is considered to indicate uniformity across an acceptable sample size (Fowler *et al.* 1998).

The FCV 1960-1975 flower and budding report (summary data in **Figure 53**) recorded an average of 1 in 3 moderate-heavy flowering years (M. Keatley, unpublished analysis), considered to be at intensities worthy of later seed collection.

More recent floral monitoring in Alpine Ash from 2002-2024 (**Box 1**; Bassett 2024) has revealed a similar proportion of good flowering years, with 7 of the 22 study years producing a Statewide-level mean flowering intensity of >6 million flowers/ha in Victoria (**Figure 55**)[34]. However, the incidence of good flowering was not evenly distributed in time, and it seems that a lack of flowering in Alpine Ash during a particular season can be related to the incidence of drought during that crop's period of bud initiation and early-stage development (see millennial drought period, **Figure 55**). House (1997) infers that a lack of resources like rainfall will negatively influence flowering, supporting this hypothesis.

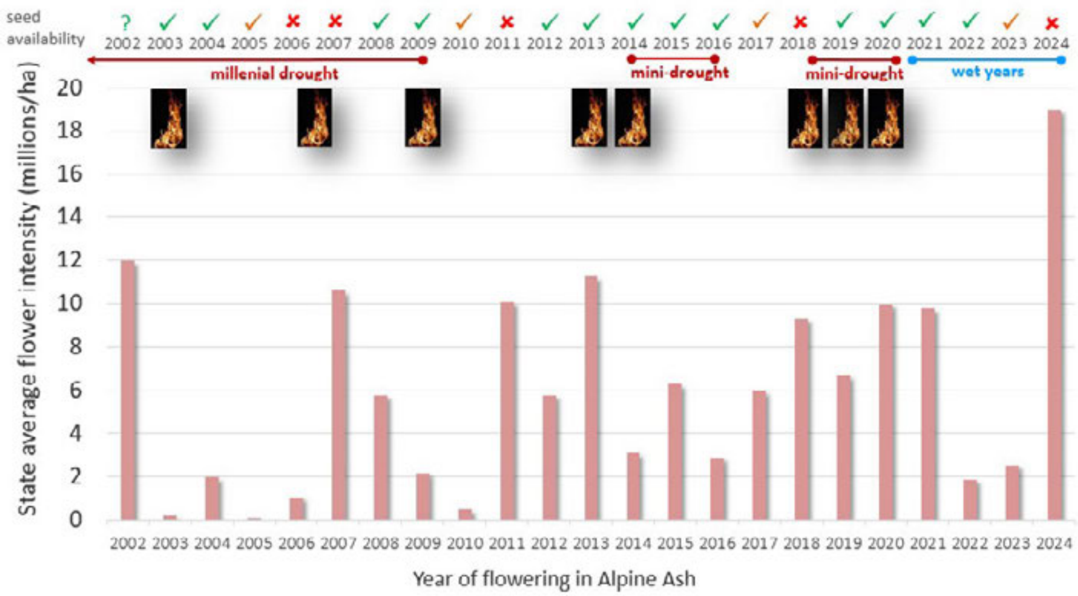

Figure 55. Recent history for mean annual flowering intensity of Alpine Ash in Victoria, based on extensive operculum monitoring (n = 13 long-term sites established across Victoria's Central Highlands and far NE). The incidence of drought, major bushfires and annual seed availability is also shown against flowering intensity. This data is collected as part of a long term flower and seed forecasting program (see NFSG No. 1-v2 for techniques (Bassett 2011), and Bassett (2024) for the latest flowering forecast). Seed availability relates to seed collection and the indicators shown follow intuitive traffic light colours as follows: ✓= Effective seed crops; ✓= limited seed crops; × = no effective seed crops.

[34] Considered the minimum flowering intensity to produce collectable seed crops 1-3 years later (see **Figure 44**).

Spatial variation of flowering intensity in mature Alpine Ash

At the State-wide scale, Alpine Ash has consistently expressed particular flowering patterns over the last two decades, with five distinct ‘flowering regions’ based on flowering pattern: (1) Central Highlands north (Alexandra/Marysville); (2) Central Highlands south (Noojee/Erica); (3) The 4-peaks (Mt’s Stirling, Timbertop, Skene to Useful); (4) far NE Victoria (Ovens/Corryong); and (5) Dargo into East Gippsland (**Figure 56**).

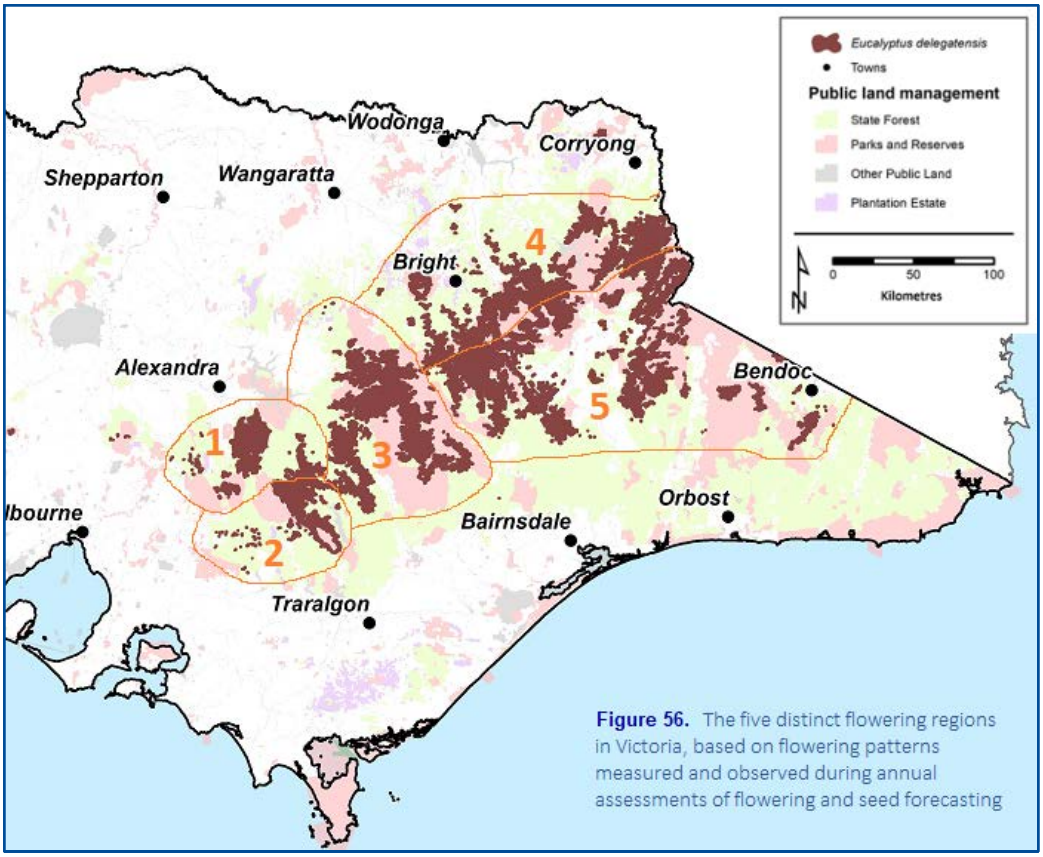

Figure 56. The five distinct flowering regions in Victoria, based on flowering patterns measured and observed during annual assessments of flowering and seed forecasting

Although flowering period is usually synchronised between these regions, being confined to a common 3-5 week period, their intensity rarely is and will vary according to the following patterns (based on seed floral monitoring and seed forecasting techniques in Bassett 2011; Bassett 2021 to 2024; Bassett 2021b):

- The incidence of heavy flowering intensity in the Central Highlands north and south of the Great Dividing Range is rarely synchronised, and in most years flips annually between each region. Within the decade shown in **Figure 57**, only seasons 2017 and 2021 experienced similar levels of flowering intensity north and south of the Divide, although both regions in 2014, 2022 and 2023 concurrently flowered poorly.

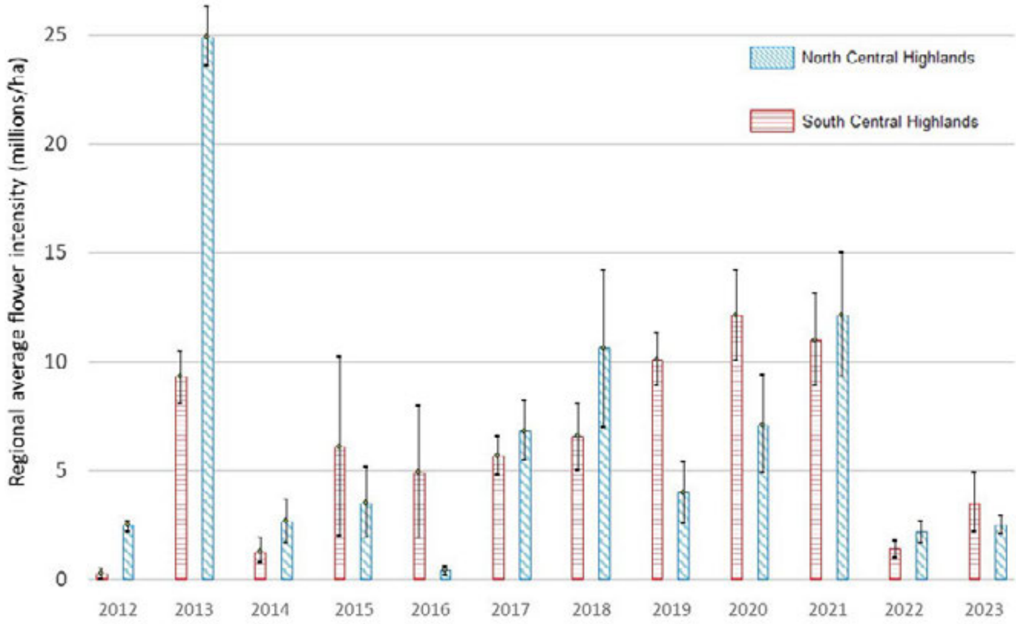

Figure 57. A comparison of annual Alpine Ash flowering intensity between north and south Central Highlands 'flowering regions' over the last decade. Standard error bars indicate trends in significant difference or otherwise, and also indicate levels of within-season variation by flower region. For example, flowering crops in 2015 and 2016 were highly variable south of the Divide (Bassett 2023).

- In the Hume Region of Victoria prior to the 2020 bushfires (flower regions 3 and 4 north of the Great Divide; **Figure 56**), aerial flowering assessments indicated that flowering over the previous 20 years have generally began in the far north-east, from Mt Pinnibar back west to Mt Timbertop, then 'rolled-out' in a westerly and southerly direction.
- Flowering pattern across 'The 4-peaks' (flower region 3) can be consistent; being either sporadic throughout, or each producing at least one 'Heavy' patch within a season, or good widespread flowering throughout unlinked to other regions – this latter tending to occur every 3-4 years. Flowering often begins first at Mts Stirling and Timbertop during December with a January peak elsewhere, or in January with a February peak elsewhere.
- Flowering in the Dargo to East Gippsland region occurs more consistently than in other parts of the Alpine Ash distribution. For example, good flowering somewhere on the Nunniong Plateau occurs almost *every year*, with very positive implications for seed collection there. This cannot be said for the other four flowering regions.
- Within season, regional flowering can be very variable, indicated by large error bars in some seasons (**Figure 57**), corresponding to coefficients of variation of 70-80% or greater. Resulting seed crops are therefore sporadic and difficult to locate without aerial data and consistent forecasting is required to pick up these variations.

Factors influencing flowering behaviour and success

Budding leads to flowering (**Figure 2**), and given buds are present in Alpine Ash crowns for a significant period (as inflorescence for 15-16 months; as umbel buds for a further 13-14 months), most influences on potential flowering intensity occur during the budding and flowering period, including the following factors based on **Figure 55** and other observations, measurements, and historical literature on the subject:

- Flower abortion has been monitored during Victoria's current flower and seed forecast program throughout the last decade. Until 2021 no unusual widespread abortions had occurred (see **Box 9**), with up to 40% of heavy flower-crops being usually lost in the first 4 months. Such losses are normal for eucalypts, for example see Gill (1966), Loneragen (1979), Bridges (1983) and Bassett (2002); with a general rule being 'the heavier the crop, the lower the proportional loss' (Aston 1975; Cremer *et al.* 1978; Florence 1996).
- Drought, being the lack of effective rainfall, has perhaps the most significant impact on flowering success at the landscape level. "Effective rainfall" refers to a rainfall quantity and frequency that produces sufficient soil moisture to support the species' tree physiology. Bud initiation is impacted by dry conditions, leading to an absence of productive flowering two seasons later. For example, Alpine Ash flowering was frequently impacted by severe drought from 1998 to 2020 (**Figure 55**). This impact has also been reported for Mountain Ash (Bassett 2011; Flint & Fagg 2007; Bassett 2023) and other eucalypts (Loneragen 1979; Bassett 2002; Somerville & Nicholson 2005).
- Both intensity and/or duration of drought can influence flowering. **Figure 55** indicates that flowering of Alpine Ash in Victoria was supressed by the millennial drought, resulting in poor seed crops at the time of the 2006/07 bushfires (Fagg *et al.* 2013), producing a landscape of sporadic natural Ash regrowth where mature Ash was fire-killed (O. Bassett aerial observations annually post 2006/07).
- It is noteworthy that during the millennial drought, following four light years of flowering from 2003 to 2006 inclusive, Alpine Ash was able to flower heavily in 2007, producing enough seed for mature Ash forests to naturally recover following the 2009 bushfires (Fagg *et al.* 2013). Clearly the factors that trigger flowering extend beyond drought influence only and are likely related to more complex adaptive strategies in tree physiology35F[35], enabling a flowering event to eventually occur, even during extended drought. These more complex factors are not well understood, requiring continued collaboration between agencies that study eucalypt flowering, including apiarists (**Box 10**).

[35] The late Dr David Ashton, an earlier pioneer of eucalypt floral research (Aston 1975) was convinced that a 'life-time' period of research would be needed to understand flowering behaviour (personal communication to O. Bassett, 1990). We are still learning new aspects today.

Box 9. Growth or reproduction?

Recent observations in Alpine Ash since 2020 indicate that ongoing rainfall over summer can extend the growing season, impacting the success of flowering and seed production.

Axillary budding in new leaf/tip growth in Alpine Ash depends on effective rainfall during the spring months. However, if that rainfall extends throughout summer and into autumn, leaf/tip growth may also continue (see Box 7), with energy diverted from seed production into significant tree growth, resulting in the abortion of developing flower crops (even if heavy) and the temporary cessation of reproductive activity.

This occurred to the heavy 2021 flowering crop, as recorded by Bassett (2021 and 2021b), with significant tip leaf-growth into early 2022, accompanied by continuous abortion of under-developed flowers at some floral monitoring sites from February to December of 2021 (Bassett 2022 & 2023). By March 2022, the predicted seed crop intended for collection was absent in some localities, such as Upper Yarra, Blue Range and parts of Matlock.

During 2021, abortion of floral components occurred at all other stages, not just flowering. Umbel bud crops due to flower in 2022 and inflorescence bud crops due to flower in 2023 were also aborted, with a reduced supply of seed in 2023 and predicted shortfall in 2024.

- The millennial drought ended by close 2009, with effective rainfall supporting extensive flowering by 2011. This crop provided a mature seed source for Alpine Ash recovery following the 2013 Harrietville-Alpine bushfires (Bassett *et al.* 2015).
- The mini-drought which centred on 2014 also impacted budding intensity, leading to a shortage of canopy seed in Alpine Ash by early 2018 (**Figure 55**). It was fortunate that no large bushfires occurred in 2018. But a relatively small fire in the Alpine National Park did occur, creating a small area of predicted population collapse (Bassett & Galey 2018).
- Effective rainfall in 2016 proved to be significant in the recent history of Alpine Ash flowering and the persistence of the species over much of its range. Successful bud initiation in that year occurred as a result, producing good flowering in 2018. This addressed that years' seed shortage by providing extensive seed crops in mature Alpine Ash during the 2019-2021 period. Concurrent with this was the most severe drought intensity ever recorded during summer/autumn 2019[36], leading to the 2019 and infamous 2020 Black Summer bushfires. About one quarter of Victoria's Alpine Ash extent was burnt over two seasons, and the presence of good seed cops (Lutze & Bassett 2020) is expected to result in extensive Ash regrowth where mature forest was killed during those two years (Bassett & Galey 2019; Bassett *et al.* 2021).

[36] Bryam-Keetch Drought Index (BKDI) in the extreme; 170 being the highest recorded since monitoring began for floral studies in 1994 (Bassett 2023).

- It was not until mid-2020 that longer term, effective rainfall was established. It remained until at least 2023, although reducing into 2024, but providing an opportunity to study flowering behaviour during a period of extended rainfall. **Boxes 7 & 9** provide an overview, and the following four conclusions are adapted from Bassett (2024):

  Four distinct climatic periods over the last 30 years have been identified based on their impact on flowering behaviour, and these broadly describe the drought/rainfall combinations that are possible:

  (1) 1994 to 1997 (4 years: period of average rainfall / 'intermittent dry and wet,

  (2) 1998 to 2009 (12 years: millennial drought as 'extended dry period'),

  (3) 2010 to early 2020 (10 years – 'return to intermittent dry and wet' as in (1)),

  (4) April-2020 to mid-2024 (4 years – 'extended wet period').

  Bassett (2022; 2023) describe climate during these periods, and the impacts of these climatic conditions on flowering behaviour are labelled as Types in **Table 5**.

Table 5. Flowering behaviour for Ash species recorded in Victoria's long-term floral and seed forecast project at the landscape scale over 30 years, and the corresponding climatic triggers for flowering initiation or cessation (from Bassett 2024).

Behaviour	Description	Climatic trigger
Type-1	Drought supresses bud initiation, resulting in a lack of flowering 12-18 months later	extended dry period (6 months or more)
Type-2a	Rainfall immediately after drought triggers budding, producing flowering 12-18 months later	intermittent dry/wet periods (measured in months only)
Type-3	Extended rainfall following drought can supress budding, or abort flowers, by switching tree physiology from reproduction to growth, resulting in a lack of flowering 12-18 months later	extended wet period (two or more consecutive wet seasons after drought)
Type-2b	A return to rainfall after dry encourages an eventual return to biennial flowering; re-establishing the natural flowering cycle of both species when soil moisture is not limiting.	ongoing wet/dry period (two or more wet seasons after drought)

- The most frequent flowering behaviour expected for Alpine Ash is Type-2a, producing effective flowering crops every 2-3 years. This is because extended or ongoing droughts and rainfall periods are both relatively rare, even in the current climate change context, with intermittent dry/wet periods more common, albeit with likely extremes.

- Given Alpine Ash is a high elevation species, bud crops are also subject to severe alpine weather conditions, with wind, rain and snow impacting any stage of seed crop development, including pollination. Such impacts can be widespread.

Box 10. The value of Alpine Ash to the Apiary Industry

The dominant nectar source of Australian honey is *Eucalyptus* (Sniderman *et al.* 2018). Although not favoured as a primary species, Alpine Ash can be useful to the apiary industry as a source of nectar and pollen for honeybees. Honey produced from Alpine Ash is quite strong and may taste bitter, perhaps needing an 'acquired taste'. However, Alpine Ash nectar and pollen yields are heavy (Goodman 1973; Somerville 2019), and NSW apiarists report an average annual honey yield of 40 kg/hive (Somerville & Nicholson 2005).

The species is therefore an excellent 'fall-back' for feeding bees during seasons when other more favoured eucalypt species are not performing. In fact, the Victorian Apiarists Association (VAA) believes Alpine Ash has been underutilised by its beekeeper members and has encouraged them to consider this species as part of a healthy regime for seasonal hive management (Mr. Ian Cane *pers. comm.*). This willingness to consider a wider range of flowering species is needed given more frequent bushfires (Fairman *et al.* 2016) and reductions in eucalypt flowering frequency due to more frequent droughts (Rawal *et al.* 2015; Wrigley & Fagg 2010; and **Figure 54**, possible cause based on the O. Bassett data set - see Bassett 2011 and 2021-2023).

Apiarists are a key source of knowledge about eucalypt flowering patterns, given their productivity depends on their attention to the natural rhythms of this resource.

- Ashton (1975a) reports severe competition for resources like space and nutrients between umbellate buds in Mountain Ash, the general physiology of which is agreed by, and explained well in, Stephenson (1981). An inspection of most umbels will reveal pedicel scars where umbellate buds have abscised and fallen away (Bassett 2002). It is reasonable to assume that this same competition for resources occurs in Alpine Ash.
- Grose (1957) was first to notice localised loss of bud or flowering crops in Alpine Ash, reporting that a species of Lerp locally decimated umbel bud crops in parts of his study range, with buds aborted from tree crowns prior to flowering.
- Wasps (*Megastigmus* genus) are also known to lay eggs in the floral tube of umbellate buds, causing them to abort prior to flowering, with the common evidence of this being larval exit holes in aborted umbellate buds (Bassett 2011). However, abortion due to wasp attack can also occur at any stage of capsule development post-flowering, with larvae feeding on early developing ovules or later seed particles.
- Parrots and Cockatoos can be responsible for decimating whole flower crops on individual trees while feeding on nectar or the succulent developing ovules soon after flowering (Bassett 2011). Cockatoos can also decimate seed crops (**Page 71**).

The reproductive age of Alpine Ash

Given Ash species are obligate seeders and easily fire killed (see **Chapters 3 & 4**; Bowman & Kirkpatrick 1986; Fairman *et. al.* 2016), knowing the age of reproductive maturity, or when young Ash has the capacity to flower and set sufficient seed, is critical for understanding the fate of regrowth killed by bushfire and the potential for localised or more widespread population collapse. *This issue is now critical to forest management in Victoria given the rapidly expanding extent of young Ash forests regenerating after frequent bushfires during the period 1998-2020* (Bassett *et al.* 2021; Fairman 2022; Bartlett *et al.* 2022). There is an age below which Alpine Ash cannot naturally recover due to the lack of canopy seed development, and a major problem for forest managers today is the frequency of short-interval, overlapping bushfires occurring at less than reproductive age (Bowman *et al.* 2014; Fairman *et. al.* 2016).

Reproductive age for Alpine Ash is currently considered by forest managers to be 20 years (Bassett 2011; Lutze & Bassett 2020). The issue has been known since the 1950s (Jacobs 1955), with Grose (1957) finding that less than 1% of seed by weight came from younger, suppressed trees on a harvested stand. Cremer *et al.* (1978) concurs, reporting that Alpine Ash can produce seed by age 10, but usually not in sufficient quantities. More recently following the 2009 Black Saturday bushfires, only one small area of Alpine Ash at age 15 years was found to hold sufficient seed for natural recovery (Bassett 2009a). Doherty *et al.* (2017) also noted 'precocious flowering' in Alpine Ash as young as 6 years of age, although the resulting seed had very low viability. Such early flowerers are usually widely spaced, causing inbreeding (House 2005) and resulting in low seed quality[37]. This concurrence of small crops and low seed quality means that seed on immature Alpine Ash trees is usually unreliable for forest regeneration following bushfire.

The question of seed contribution from immature regrowth arose again after the 2020 Black Summer bushfires. The extent of damage to the immature cohort of Alpine Ash in Victoria was so large following these fires, that the State government undertook a strategic seed crop assessment (SSCA) to determine the level of contribution of seed from burnt immature stands. It was found that immature Alpine Ash, predominantly of 2003 origin (age 17 years), had 50,000 seed/ha in canopy, with a high level of variation (Lutze & Bassett 2020), representing as little as 3% of the seed quantity commonly found in a mature canopy of pure Alpine Ash. This was inadequate, given a median of at least 100,000 vs/ha held within canopy capsules are required for ecological stocking, and a median 300,000 vs/ha to achieve full stocking (data based on Bassett 2011 and Bassett *et al.* 2014b). The quality of this 2003-origon seed was also unknown, so additional aerial sowing was undertaken to ensure these stands recovered from likely population collapse (**Chapter 7**; **Figure 18**; Lutze & Bassett 2020; Bassett *et al.* 2021).

[37] Inbreeding is a high level of self-pollination, leading to an 'inbreeding depression'. The seed from such a breeding depression is usually characterised by low viability and vitality (see NFSG No. 1, Bassett 2011).

4.1.3. Capsule development and seed shed

Once flowers are pollinated and stamens and stigmas fall, capsules (fruit) develop over a 12-14 month period. The floral tube swells and begins turning red/brown but remains fleshy and green for the first 2-3 months as seeds develop and the disc begins to brown (**Figure 58**). Adequate maturity is not expected until March of the next calendar year after flowering, at which time seed is known as '1st year seed' (**Figure 48**). Within the developing seed crop, especially if it is a heavy crop, a proportion of seed can mature earlier, and is capable of producing regrowth after bushfire as early as January (Bassett 2009). However, collection and storage of this seed should not occur prior to March to ensure adequate seed maturity.

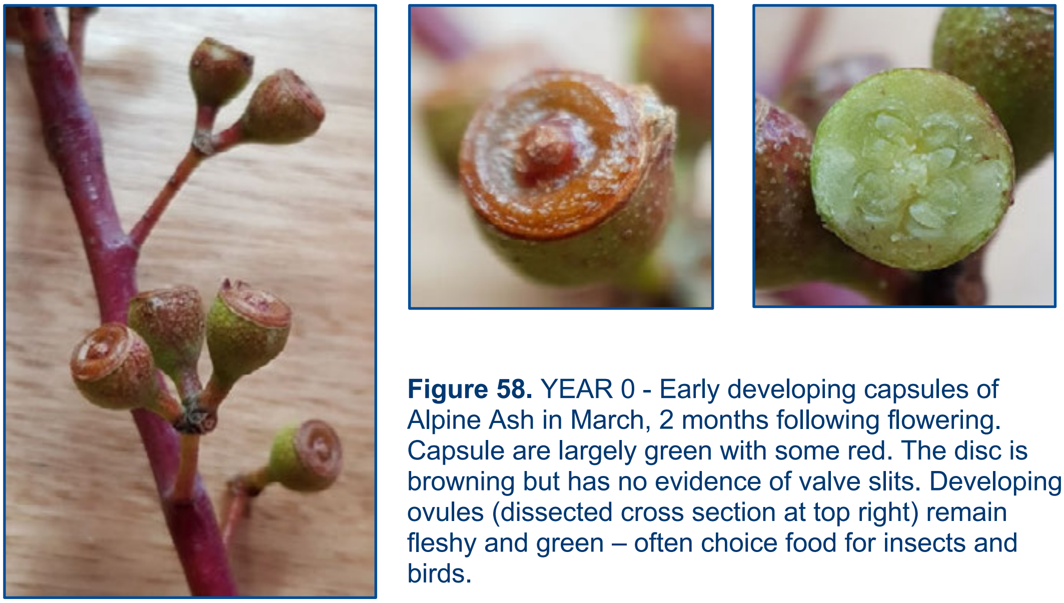

Figure 58. YEAR 0 - Early developing capsules of Alpine Ash in March, 2 months following flowering. Capsule are largely green with some red. The disc is browning but has no evidence of valve slits. Developing ovules (dissected cross section at top right) remain fleshy and green – often choice food for insects and birds.

Throughout the first year of development, capsule shape develops quickly during late summer into autumn. This perhaps explains the earlier (January/February) timing of flowering in Alpine Ash compared to Mountain Ash (April) at its lower elevation. A longer period is required during warmer months for capsule maturity and consolidation on the tree prior to the first winter. By November, valve slits are evident and seed can spill if stems die. Capsules can still be associated with leaves. However, seed remains immature and green in appearance (**Figure 59**). This seed will not naturally disseminate unless the capsule bearing twig is killed, and most seeds will not germinate at this early stage (Grose 1957).

By the following March, 1st year capsules have swollen to take on the full pear-shape of mature capsules, although they will continue to enlarge beyond 1st year for a further 12 months. Capsules are clear of leaves and are woodier with a more swollen disc and observable valve slits. Seed is light brown, with some darker particles. Note the cross section remains somewhat fleshy (**Figure 60**).

Figure 59. YEAR 0 – Developing capsules of Alpine Ash during November, 10 months after flowering. Capsules remain green, but have formed woody rims and discs on which valves can open and shed seed. Seed remains green in colour with orange chaff at this immature stage. This seed is not collectable and most will not germinate successfully. Note: sample is slightly dry, not fresh.

1st year Alpine Ash seed is collectable, but note the following important characteristics:

- The seed can be viable, but can test with poor vitality (germination % < 80). Alpine Ash seed will improve in quality if left for a further 4 months or collected as '2nd year seed'.
- The seed may not store well. While in storage, it can lose both vitality and viability within the first 2-3 years, significantly reducing germination performance. This occurred to 1st year seed collected in 2003 and used following the 2006/07 bushfires (Fagg *et al.* 2013; also refer to **Box 11** for an important, recent example of using 1st year seed).
- The seed in canopy will not release following mild fire, nor will it naturally disseminate. For any seed to be released, the branch on which 1st year seed is held must first die.

By the second year, capsules will darken in colour with less green shades and largely take on the classic Alpine Ash reddish hue (**Figure 61**). They will be affixed to older, larger and woodier stems, often with bark peeling off in flakes around autumn. Seed will appear fully mature with a higher proportion of darker particles. Chaff will lose the bright orange appearance that is typical of younger capsules (see **Figure 59, then 60**)[38].

[38] 'Chaff' are dead ovular structures made up of sterile 'ovulodes' and live ovules which have not been fertilised. Most chaff occur at the top of the placentae, towards the valve openings. In this way, most viable seed occur deep in the capsule body (Boland *et al.* 1980), providing protection during fire and delayed release after fire.

Box 11. Collection of 1st year seed in 2003

During 2003, five tonnes of 1st year Alpine Ash seed, originating from the 2002 flowering, was collected for forest recovery following the Alpine bushfires of that year. Collection began in the Mansfield district from early to mid-March 2003. These seed crops had developed from an extensive flowering in January 2002, with the first-ever aerial flowering assessments for this species fortunately locating suitable collection sites one year prior to the bushfire. Only half of this seed was sown in 2003, with 2.5 tonnes of it remaining in storage at 15°C.

Following the 2006/07 bushfires, the stored seed was entirely used for recovering immature fired killed Ash regrowth (IFKAR; Fagg *et al.* 2013) and areas salvaged for timber (Theobald & Lawlor 2006). This included the Connors Plains area to the north of Licola and Mt Useful.

This seed failed to germinate and/or establish across large areas of the landscape, leading to the need for reforestation at Connors Plains (see **Box 14** in **Chapter 7**).

Two compelling reasons for these regeneration failures are implicated amongst other factors (Fagg *et al.* 2013):

(1) Winter during 2007 was mild with little snow falling and insufficient stratification of seed. The sown seed remained dormant with little germination in the following spring;

(2) Vitality of these seed-lots declined while in storage from 2003 to 2007.

Both these problems contributed to widespread regeneration failures during 2007/08.

Seed lot test examples, comparing 2003 tests with 2007 retests

- Seed lot 'MAN0304AA23' – in 2003 tested 96% germination % at 1.25 kg/ha, then retested in 2007 with 75% germination and 1.67 kg/ha
- Seed lot 'MVLAA 03-05' collected December 2003, tested 85% germination, retested in 2007 prior to sowing at a vitality of only 44% germination.

Using this same seed, the then Department of Sustainability and Environment (DSE) also ordered 83,000 nursery seedlings in 2003, producing 20,000 germinations. In 2007 DSE again ordered 80,000 seedlings using the same stored seed, producing only 7,000 germinations.

Management response

This experience triggered seed management improvements for Alpine Ash, once thought to be quite straightforward, leading to more refined planning when seed forecasting and a preference for not collecting and using 1st year seed collected prior to spring. Preference is given to collecting a mix of seed ages where they occur and, if collecting all age crops, then only where 1st year seed is late in the season. Note that since 2007, seed storage prescriptions have also been tightened, reducing storage temperatures from 15°C down to 4°C.

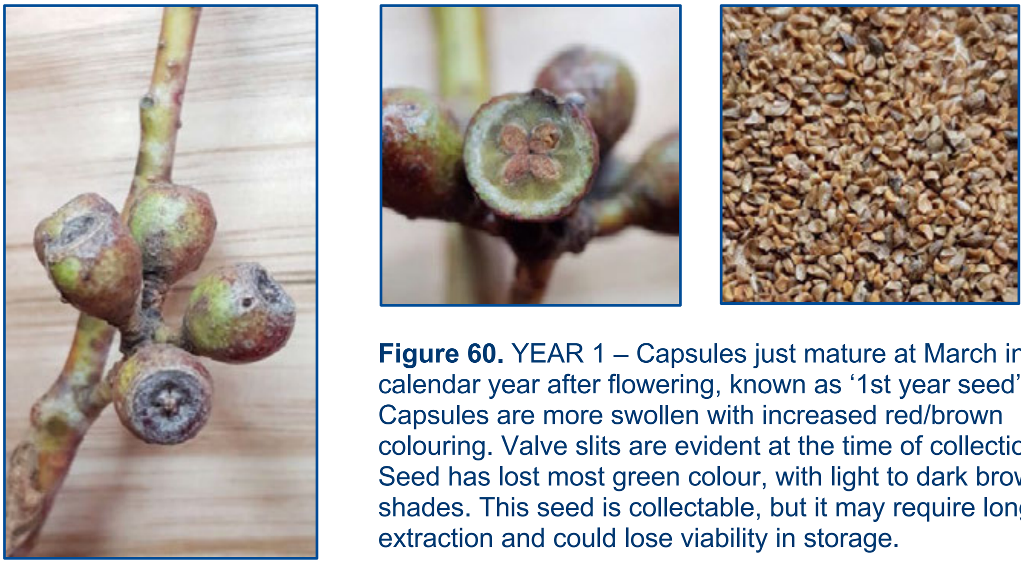

Figure 60. YEAR 1 – Capsules just mature at March in the calendar year after flowering, known as ‘1st year seed’. Capsules are more swollen with increased red/brown colouring. Valve slits are evident at the time of collection. Seed has lost most green colour, with light to dark brown shades. This seed is collectable, but it may require longer extraction and could lose viability in storage.

2nd year seed (**Figure 60**) is the most valuable for collection and storage, given it has these following important characteristics:

- The seed reaches peak vitality, and may germinate with more vigour than 1st year seed.
- Seed yield will be its highest from 2nd year seed (4-7%). Seeds are larger with more weight, likely producing germinants with more vigour for this reason also.
- Natural dissemination has not yet started to significantly erode seed yield from collected capsules. This is usually expected from 3rd year crops.
- The seed will easily shed under mild fire heat, unlike 1st year seed. Some natural dissemination will begin, but only in small quantities.

Figure 61. YEAR 2 - Capsules fully mature 2 years after flowering, known as ‘2nd year seed’. Green colouration on capsules has disappeared, now appearing in the classic ‘Alpine Ash red’. Seed has slightly darkened. Valves easily visible with grey/woody disc. Seed yield highest from 2nd year capsules. Seed will begin to naturally disseminate from tree crowns, but will not peak until 3rd year.

Early 3rd year seed (not pictured here) is also valuable for collection, and capsules and seed will appear similar to 2nd year seed, but will be held on larger diameter and progressively woodier stems further down the branch. The most important problem when collecting 3rd year seed is related to seed yield as follows:

- By late summer into autumn the seed begins to naturally shed from 3rd year capsules as capsule bearing twigs naturally die or hot weather dries woody capsule walls, first established by Fielding (1956) and Grose (1960b). For this reason, seed yield during extraction is expected to decline from 3rd year crops collected later in the season.
- Another reason seed yield during extraction will decline in the 3rd year is that capsule material from this age crop will hold more woody material, with some twig diameters exceeding 10 mm. Care should be taken when collecting 3rd year crops to exclude excess large woody material from the bale (NFSG No. 2, edition 2 - *in prep*. 2025)[39].

4.1.4. Seed quantities and dispersal

A recent study by O. Bassett in 2021 of Alpine Ash capsule material collected into wool-bales from Nunniong Plateau (Swifts Creek district) and Silvermine Spur (Mansfield district) examined the seed from 6,201 capsules attached to 130 twig samples taken randomly from 12 bales. Material was sourced largely from 2018 and 2019 flowered crops, with a small amount of 2020 crop included, producing a good mix of mostly 2nd and 3rd year seed. Excluding 1st year capsules, fully matured capsules had an average diameter range of 7.6 - 8.2 mm with an average total seed and chaff weight content of 2.4 g per 100 capsules. Grose & Zimmer (1958) reported for Alpine Ash an average of 3.7 viable seeds (vs) per capsule, with range 1.7 - 6.9.

Alpine Ash has a recorded ‘Statewide average’ viability of 100,000 vs/kg (VicForests’ seed testing database), close to the 107,000 vs/kg reported by Boland *et al.* (1980). The spatial variability in seed viability possible in the landscape was demonstrated following seed tests undertaken on 27 seed-lots by Forest Solutions to ISTA standards at the State’s Laverton North seed facility in 2022. Seed-lots were collected during 2020/21, with viability results ranging from 50,000 vs/kg up to 142,500 vs/kg and variation of mean by locality (**Table 6**).

Canopy seed crop production and its seasonal variation

Mature stands of Alpine Ash can produce up to 25 million flowers/ha, but with extreme seasonal variation (**Figures 55 & 57**). Good flowering years typically result in canopy seed quantities in the order of 1 to 4 million viable seeds/ha. A review of various landscape-level strategic seed crop assessments in Victoria following bushfires provides examples of the temporal variation involved. After the Great Divide bushfire in 2006/07, the largest seed crop assessment ever undertaken occurred with 680 plots located throughout Alpine Ash (**Table 7**) and 120 in Mountain Ash within the bushfire extent. Seed supply was predicted to be light in 2007 (Bassett 2005), based on little

[39] NFSG No. 2 (Wallace 1994) remains available but is being updated by Forest Solutions following the 2020 Black Summer bushfires (Bassett and Hansby *in prep.* expected 2025).

flowering recorded in years leading up to the bushfire (**Figure 55**). The most recent flowering that had occurred during this period was in 2002, from which all canopy seed had been exhausted through natural seedfall by 2005/06. Crops were assessed as Very-light to Light in mature stands, with a median range of 15,000 to 267,000 vs/ha available at the time of the fire. Normally, canopy seed storage in mature Ash may average several million per hectare, but up to 10 million (Bassett 2011).

Table 6. A range of seed viabilities recorded within and between different sites of Alpine Ash. Seed-lots were collected during the 2020/21 season, extracted, and then recently tested at the Laverton North seed extraction facility. Tests were undertaken by Forest Solutions for VicForests and DEECA.

Site	District	No of seed lots	Total seed weight (kg)	mean viability (vs/kg)	range (vs/kg)
Mt St Gwinear	Erica	14	318	124,000	100,500 - 142,500
Silvermine Spur	Mansfield	4	59	65,500	50,000 - 75,000
Ezards Tk	Swifts Ck	4	56	90,500	50,000 - 122,000
Nunnett Rd	Swifts Ck	3	27	105,000	90,000 - 123,500
Soufflé coupe	Marysville	2	38	105,000	96,000 - 114,000

As in 2006/07, poor crops were also forecast to be present at the time of the 2018 Tamboritha-Dingo Hill bushfire in the Alpine National Park (**Table 7**; Bassett & Galey 2018).

In contrast, seed crops following the 2003, 2009, 2013, 2019 and 2020 bushfires were heavy (**Table 7**), having developed from earlier effective flowerings. Seed crop assessments indicated median seed crops to range from 0.6 to 6.8 million vs/ha (Fagg *et al.* 2013; Bassett *et al.* 2015; Bassett & Galey 2019; Bassett *et al.* 2021).

As an overall summary of annual seed availability in recent years, seed quantities that could support large scale collection operations have been widely available in the landscape on average 3 in 5 years (see **Figure 55** 'seed availability' timeline), or 60% of years. This pointedly implies an absence of seed availability during 2 out of every 5 years (4 years in a decade), highlighting the need for good planning and seed forecasting to:

(1) Predict and plan for when good seed years will occur; and

(2) Actively seek isolated crop locations in the lighter years, so some level of collection in those light/sporadic years can be maintained. This latter is needed to sustain an ongoing seed collection program and workforce (see NFSG No. 2, second edition due 2024).

Table 7. Canopy seed availability (quantity) in Alpine Ash at the time of various bushfires over the last two decades. Plot numbers are for Strategic Seed Crop Assessments (SSCA) in mature Alpine Ash within the years undertaken. Data in red is from SSCA projects by season. SSCAs were not needed in 2003, 2013, 2018 and 2019.

Year	Fire name	Alpine Ash impacted (ha)	Seed crop Forecast	SSCA yes/no (plot No.)	Seed crop (millions vs/ha)
2003	Alpine	81,000	heavy	no	*1.0 – 5.0
2006/07	Great Divide	118,000	light	yes (680)	0.0 - 0.2
2009	Black Saturday	43,000	heavy	yes (84)	0.6 - 2.9
2013	Harrietville-Alpine	15,300	heavy	no	*1.0 – 4.0
2018	Tamboritha-Dingo Hill	2,500	light	no	*0.0 - 0.5
2019	2019 fires, various	12,300	heavy	no	*1.0 – 4.0
2020	Black Summer	88,000	heavy	yes (77)	0.8 - 6.8

*Estimate based on measured flowerings 1-3 years earlier. Otherwise based on assessment of seed crops in the field (SSCA). Sources: Bassett (2009a); Fagg *et al.* (2013); Bassett *et al.* (2015); Bassett & Galey (2018); Bassett & Galey (2019); Lutze & Bassett (2020); Bassett *et al.* (2021).

Spatial variation of seed crops within season

Table 7 and **Figure 57** indicate that Alpine Ash seed crops can vary widely, even in 'heavy' seed years. However, the implications for forest management depend on the following factors (Poynter *et al.* 2009; Bassett 2011; Wallace 1994 & Bassett *et al in prep.* 2022):

- For forest recovery following bushfire, 'Moderate' to 'Heavy' seed years provide a buffer in spatial variation, with even the minimum quantities shown in **Table 7** (600,000 to 800,000 vs/ha) being adequate to naturally recover Ash forest.
- For forest recovery, 'Light' seed years lack this buffer. For example, many locations with mature Ash forest in 2006/07 had insufficient seed to naturally recover following the Great Alpine fire. In such years, assessments are required to identify these areas, given intervention using aerial sowing may be required to avoid localised population collapse.
- For seed collection, the spatial variation in all years is problematic regardless of predicted intensity. To maximise productivity, seed collection in 'Moderate' or 'Heavy' years needs to be focused on the best seed crops available, and predicting their location will require aerial flowering assessments and ground-based verification prior to collection (see NFSG 2, edition 2).
- Although predicted 'Light' years are not good for seed collection, monitoring spatial variation may locate pockets of 'moderate' intensity crop adequate for collection.

The fate of Alpine Ash seed following maturity in capsules

Once seed is mature, about 14-15 months after flowering, the majority of seed will be held in-canopy for at least 2-3 seasons (**Figure 48**), and sometimes 4 seasons – by then in woody capsules, depleted in number and associated with large diameter twigs. Fielding (1956) reports that the peduncles of these older crops can often be found ingrown on branches.

Perhaps only half or less of the matured seed will be successfully retained to naturally disseminate from opened capsules, mostly in the late summer to autumn of their 3rd and 4th years, spreading up to one tree height away (Grose 1960b; Cremer *et al.* 1978; Florence 1996). This is because Alpine Ash seed is also subject to insect attack and the vagaries of severe weather at high elevation. Boland & Martensz (1981) in their study of seed losses from 90 Alpine Ash trees across 18 localities found an average of 20% of capsule seed content to be destroyed, largely by wasp larvae. At the tree level, crops can be also decimated by feeding Cockatoos (**Figure 62**). Earlier, Grose (1960b) had found the same, with 15-20% losses to small wasp species from three Genera: *Ditropinoltella, Megastigmus* and *Uriellomyia*.

Given Alpine Ash is a high elevation specialist (**Chapters 1 & 3**), the species is also subject to severe weather events, including winds and snow. Both these agents directly impact and dislodge capsules from the canopy, with Grose (1957) reporting that 30-50% of capsules with seed still enclosed fall like this prior to dissemination. Such seed is considered lost to regeneration given most will be locked in and not spill once capsules lay on the ground (Cremer *et al.* 1978).

Figure 62. Alpine Ash capsules ripped open by Cockatoos feeding on mature seed. Although most seed is lost, seed can be spilled during the feeding process, contributing to its dispersal.

Seed that is successfully disseminated from capsules in tree crowns will fall to the forest floor. Their survival and contribution to germination will depend on factors such as competition, seedbed condition, dormancy and various hostile agents such as ants and pathogens.

Fire induces seed dissemination in Alpine Ash

Being obligate seeders, and given Ash species are easily killed by moderate to heavy intensity fire (Grose 1957, 1960b, Ashton 1976; Bowman & Kirkpatrick 1986), the natural silvical strategy of Alpine Ash in Victoria is to regenerate exclusively from seed following bushfire (**Chapter 3**), with seed also required after other disturbances like timber harvesting (**Chapter 5 & 6**) and windstorms.[40] (**Chapters 3**). To enable natural regeneration after bushfire, seed crops in Alpine Ash are induced by the fire to shed at accelerated rates. If leaves and capsule bearing twigs are scorched and die, the entire seed crop will fall rapidly, beginning immediately and completing within 4 weeks

[40] Collected seed could also be used to raise seedlings in a nursery for hand planting.

(Cremer 1962; Cremer *et al.* 1978; Bassett 2011). Otherwise, moderate intensity radiant heat alone will also induce a proportion of seed to shed but over a longer period of time, with about 60% of the seed crop falling within 8 weeks. Fire-induced seed fall can recover Alpine Ash when trees are killed by fire, as long as sufficient quantities are present at the time of the fire and seed falls onto a receptive ash-bed (Bassett *et al.* 2015; Lutze & Bassett 2020; Bassett *et al.* 2021).

If seed trees or other overwood are retained following timber harvesting, the timing of seed fall from them can be managed by slash-burning to induce a sudden seedfall event for post-harvest regeneration (VicForests 2019).

4.2 Forecasting seed crops in Alpine Ash

The idea of monitoring the fall of floral components from eucalypts to forecast flowering events and predict when mature seed crops may be present in forest canopies has long been known (Ashton 1956, 1975; Grose 1960b; Cremer *et al.* 1978). However, most early authors considered the technique too laborious for routine operational use.

In Victoria, this idea was revisited when developing ground-based seed crop assessment techniques during the Silvicultural Systems Project (SSP)[41] in the late 1980s and early 1990s. Detailed floral monitoring of other species like Silvertop Ash (*E. sieberi*) (Bassett 2002), and review of earlier research and monitoring techniques in Mountain Ash (Ashton 1975), unlocked the required knowledge for later developing forecasting techniques for Mountain Ash in the early 1990s (Campbell *et al.* 1990; Bassett & Roberts 1995; Bassett 2005; Bassett 2021b). Forecast systems were then later applied to Alpine Ash in 2002 and have been used since then to routinely assist with seed collection operations and/or post-fire assessments of natural capacity for Ash forests to recover (**Box 1**; Bassett 2011). Some ongoing results from this forecasting program, for example, are used in **Figure 55**.

Victoria's annual seed forecasting system for Alpine Ash consists of four elements:

(1) Consider drought index and rainfall effectiveness in the year of bud initiation to forecast the likelihood of flowering 2 years later. A high drought index indicates that bud initiation may be impacted. Rainfall may indicate a higher likelihood of budding.

(2) Quantify the annual shed of two floral components – bract involucres and operculum. Bract shed intensity predicts flowering intensity 1 year later, and flowering intensity predicts potential seed crop density 1-3 years later

(3) Quantify the loss of flowers before they reach mature capsule stage to gauge level of abortion and the level of success of a flowering event, and

(4) Undertake an aerial flowering assessment to indicate the possible location of seed crops across the landscape 1-3 years later (see NFSG No. 1 - edition 2 for details).

[41] See Squire (1990) for introduction the SSP project, one of the largest forest-based research projects in the world at that time. Although not undertaken in Alpine Ash, many learnings are now adopted in that forest type.

4.2.1. Considering drought depth

Bud crops with the capacity to later flower successfully seem to be stimulated by good soil moisture levels at the time of bud initiation, resulting from the sudden absence of longer-term drought. Short periods of drought may not impact budding, but a longer period will because it is the more frequent rainfall that accumulates soil moisture to levels needed in a forested catchment to support stand-level flowering. **Figure 55** seems to support this notion, with an even similar but stronger relationship previously reported for Mountain Ash, especially at high elevation (Flint & Fagg 2007; Bassett 2011; Bassett 2021b). Other eucalypt species are similarly impacted in other forest types (Loneragen 1979; Bassett 2002; Keatley *et al.* 2002 Somerville & Nicholson 2005). Ashton (1975a) for Mountain Ash, and Porter (1975; 1978) for various honey producing eucalypt species, were perhaps the first to note this correlation between rainfall, budding in the year of rainfall, then flowering 1-2 years later. Although Porter's studies were about honey production and rainfall, he found rainfall positively influenced both nectar secretion and flowering intensity. It seems Alpine Ash is no different.

However, ongoing and persistent rainfall throughout summer, although rare, can potentially impact flowering in favour of growth, increasing bud and flower losses (see **Boxes 7 & 9**).

Daily Bryam Keetch Drought Index (BKDI) is used in forecasting as an indicator of drought depth in the year of expected bud initiation. BKDIs over 80 in the Central Highlands are thought to negatively impact budding success and the intensity of flowering two years later.

4.2.2. Floral component monitoring

The shedding of two key floral components are quantified monthly throughout the growing season (October to May, see **Box 8**): involucres of bracts and operculum (**Section 3.1.1**). This monitoring forms the backbone of seed crop forecasting in Alpine Ash. There is a strong correlation between inflorescence bud production and operculum fall (flowering intensity) one year later, producing a simple linear regression (y=6.8x; **Figure 63;** Bassett 2011).

The results infer that the long-term umbel bud size at the point of flowering is 6.8 umbellate buds per umbel (**Figures 50, 63**). The slope of upper and lower prediction limits indicate an umbel size range in this data set of 2-12 umbellate buds per umbel at flowering, aligning somewhat with Flora of Victoria's upper umbel size of 7-15 (VicFlora 2022).

Using this model, flowering intensity can be forecast one year ahead of time by monitoring the fall of bract involucres.

Although crops can fail at any stage throughout seed production, the strong correlation coefficient (R^2= 0.8; Fowler *et al.* 1998) indicates that annual success is strong enough to express this correlation over a 29-year period. An exception to this occurred in 2021, at which time an unusually high proportion of umbel buds were suddenly and unusually aborted from a good crop due flower in 2022. The cause was extended rainfall across two seasons, switching physiological effort from a mix reproduction and growth to exclusive growth (**Boxes 7 & 9**). This highlights a weakness in the forecasting technique, since umbellate bud losses are not quantified, resulting in the sudden and unusually large loss in 2021 being missed. Normal losses are 'built into' the model's predictive envelope by default, so future sudden and large losses need to be located by observation during sample analysis.

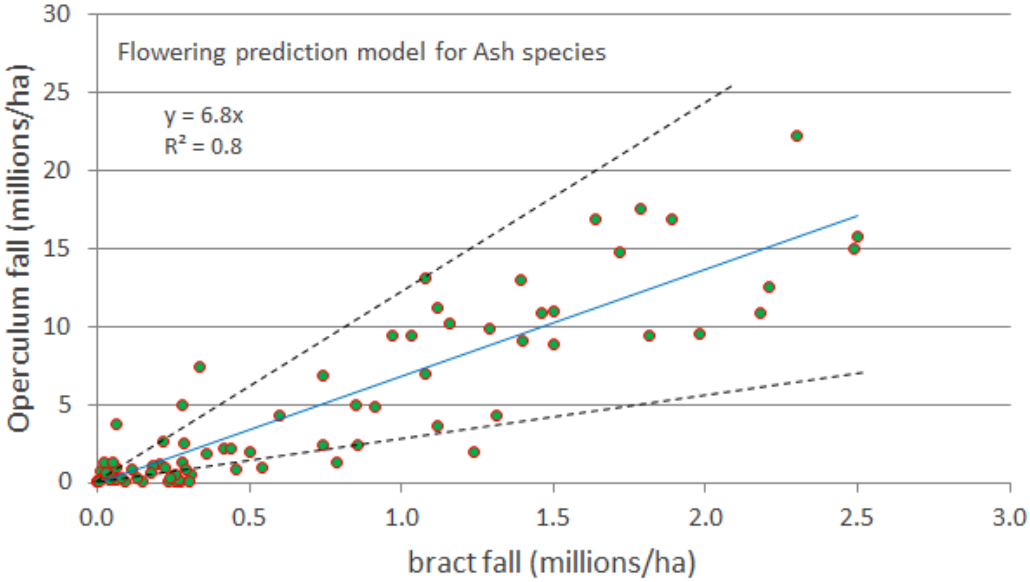

Figure 63. Regression (blue line, y=6.8x) between bract involucre fall and operculum fall one year later for Alpine Ash (20 years data) and Mountain Ash (27 years data). Includes upper and lower prediction intervals (Adapted from Bassett 2021).

Figure 64 compares the 2020 predictive floral data with actual 2019 estimates, indicating that the prediction model normally holds well for Alpine and Mountain Ash.

4.2.3. Flower losses

'Aborted flowers' refer to all flowered buds after operculum shed, including those from which stamens have shed and on which floral tubes have swollen, up to, but not including, capsules considered mature at 1st year. Developing capsules in **Figure 58**, for example, would be still considered 'flowers' if aborted. Ideally, a forecast program would monitor the fall of flowers all year. However, the current forecasting program has resource and operating constraints that only support a partial estimate of annual flower fall. Specifically, monitoring does not occur over winter due to poor conditions, meaning flower fall during this period remains unknown. At high elevations, research indicates that flower loss due to harsh winter conditions can be high (Bassett 2011; **Figure 65**).

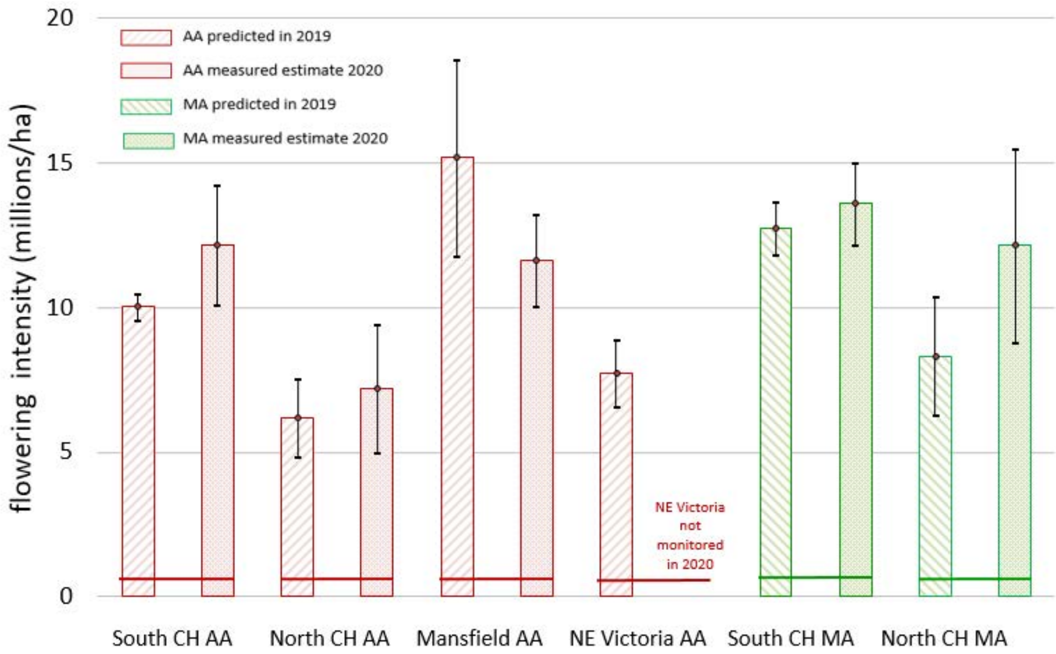

Figure 64. A comparison of Ash flowering intensity predicted during 2019 to occur in 2020, against the actual flowering intensity measured during 2020. AA = Alpine Ash; MA = Mountain Ash; CH = Central Highlands, with 'North' representing the districts of Alexandra, Toolangi and Marysville, and 'South' representing the districts of Noojee, Powelltown and Erica. Standard error bars indicate trends of significance, with all comparisons suggesting good predictive accuracy. Figure from Bassett (2021).

Accurate sampling for estimating flower fall beneath the forest canopy is also difficult given the "tall open forest" structure of Alpine Ash stands (Specht *et al.* 1974) and the tendency for Alpine Ash flowers to fall directly downwards due to their size and weight. Consequently, flowers rarely fall beyond crown projection, dictating the need for stratification in and outside crown projection when sampling. The issue has often generated a spuriously higher estimate of flower fall than operculum fall in past eucalypt floral studies, which is an impossibility given one operculum can only account for one flower (Gill 1966; Van Loon 1966; Ashton 1975; Bassett 2002).

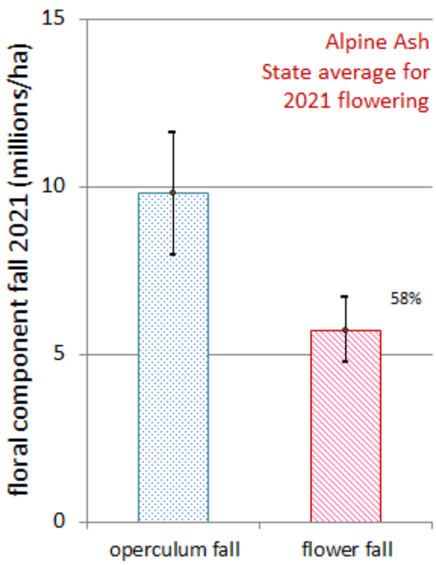

Figure 65. Comparison of flowering intensity with flower losses in Alpine Ash during 2021, modified from Bassett (2021).

In the current program, trap placement has only been random, not stratified, meaning an adjustment to flower fall estimates is required. Depending on stand characteristics, estimates are adjusted by a factor of 0.4, then doubled to account for winter losses.

Figure 65 shows an example of unusually high flower losses from the Moderate to Heavy 2021 flowered crop, averaging an estimated known 58% for the State. Based on the original estimate from Jan to March only, some stands experienced 100% abortion based on ground assessments, including the Upper Yarra for which the incomplete site estimate was 70% loss.

4.2.4. Aerial flowering assessments

Aerial flowering assessments, flown when flowering is known to be at or near its peak intensity, have been undertaken annually for Alpine Ash since 2002. Each year, a minimum of 3 four-hour flights are undertaken, and most of the Ash resource in Victoria can be covered using 4-5 flights. Maps of point flowering observations, which usually indicate stand-wide flowering, are produced to assist seed collection planning and later seed searching in the field. The flowering extent indicates the level of a forest's capacity for natural recovery should a bushfire occur up to 4 years ahead of time. Known flowering sites close to access roads and tracks indicate potential seed collection sites 1-2 years later. During seed searches, the maps significantly narrow down the search area, enabling the search crew to locate the best crops for collection while minimising search-time.

These aerial flowering assessments usually do not cover the entire Ash extent, and if peak flowering occurred at another time, flowering could be missed during these flights. In this way, the absence of flowering data does not mean an absence of seed in that area. Wider searches can therefore occur, but the known flower locations will provide a significant basis on which to build an efficient search pattern and these usually produce the majority of potential seed collection sites (refer to NFSG No. 1 and 2, second editions, for details).

Flowering assessments are undertaken using a fixed, upper-wing aircraft (**Figure 66 & Box 12**). Rotary-wing aircraft are not required and are expensive. In the past 20 years, Cessna 172 and 182 models have all been successfully used. Since 2022, Forest Solutions has occasionally used a Cessna 206 as this more powerful model provides additional capability when manoeuvring at low altitudes in steep mountainous terrain. Search patterns include contouring parallel to mountain slopes, such as at Mts Torbreck, Stirling, Skene, Useful, Baw Baw, Bogong, Wills and Baldhead, and establishing transects 4-500 m apart in more undulating terrain away from mountain peaks, such as on Nunniong Plateau.

For added safety, a twin engine such as the Cessna 337 (push-pull 'tail-dragger' configuration) is now being used as at 2025. The two engines run independently, providing a continuous power option in the event that one engine fails.

4.3 Germination of Alpine Ash seed

After falling to the forest floor, Alpine Ash seeds are subjected to a range of hostile agents, such as harvesting by ants and other insects (Grose 1957, 1963; Ashton 1981; O'Dowd & Gill 1984), soil fungal pathogens, relocation to sub-optimal niches and deep burial by overland water flow after rain events, and hostile substrates not receptive to seed; all observed during germination plot[42] monitoring over the last decade (O. Bassett observation). The successful germination of soil-borne Alpine Ash seed that survive these hostile agents will then depend on cold stratification to break dormancy.

Box 12. Recognising Ron Walpole's contribution

Annual aerial flowering assessments for Ash species and post-fire forest recovery assessments were flown by the Walpole family's aviation business from about 2000 to 2021. Don Walpole began piloting for O. Bassett (as Observer) in 2000/01, who shortly after handed the task to his Son, Ron Walpole, following his retirement from the RAAF. Ron was engaged by Forest Solutions Pty Ltd. to annually pilot these missions on behalf of VicForests and the State government during the period 2008 to 2021; the highlight being as pilot for Forest Solutions' 85,000 ha assessment of fire-impacted Ash in 2020. During this time, he also flew air operations for the State government's fire management branch. Ron retired in 2021.

Figure 66. (Above left) The now 'famous' Cessna 172 Hawk XP, registered in Victoria as VH-WKW and callsign "wiskey-kilo-wiskey", is piloted by Ron Walpole **(inset left)** circa 2002 on-route to the Mt Buffalo area, NE Victoria. **(At right)** Alpine Ash flowering in the Rubicon State Forest during January 2021, as seen by O. Bassett **(inset right)** from WKW at 600 ft a.g.l. during its final season undertaking this work, showing 70% of crowns in moderate to heavy flower. (WKW image: R. Walpole.)

42 Germination plots are 1 x 2 m plots, on which germination of individual seeds are tracked over time (NFSG No. 10, Bassett *et al.* 2014). See **Box 14, Chapter 7** for images and a project example.

4.3.1. Primary dormancy of Alpine Ash seed

Alpine Ash naturally develops a primary seed dormancy, referred to by Grose (1963) as a "specialised survival mechanism" to avoid autumn germination so new germinants are not subjected to harsh winter conditions typical of the high elevation niche occupied by the species (Pryor 1954; Grose 1957, 1963; Grose & Zimmer 1958; Close & Wilson 2002; **Box 13**).

Dormancy can only be broken by cold, moist winter conditions; the process being known as 'stratification'. And the strength of dormancy is determined by the period of stratification required to break the dormancy (Grose 1963; **see next Section**).

Box 13. Ron Grose's early work indicating a seed dormancy

To test the germination characteristics of Alpine Ash, R. Grose with assistance from W. Zimmer attempted to germinate untreated seed samples at various temperatures ranging from 11°C to 27°C in laboratory conditions. The best germination performance that was achieved, measured as the proportion of seeds to germinate ('germination percent') occurred at 17°C. However, this accounted for only 25% of viable seeds, indicating a high level of dormancy. In a trial and error approach, Grose also noted that better germination occurred after untreated seeds were incubated continuously for long periods at 5°C. Further trials at 2, 5, 7 and 10°C were therefore undertaken, producing a germination percent of about 95% at 5-7°C after 15 weeks (**Figure 67**), and 3% at 10°C over the same period. This was their first confirmation that Alpine Ash seed possesses a primary dormancy. Grose's published works from the '50s and '60s remain relevant and are much sought after as collectable literature by foresters and ecosystem scientists today (**Figure 67 right**).

For those wanting to dig deeper, a read of Grose's early work is recommended.

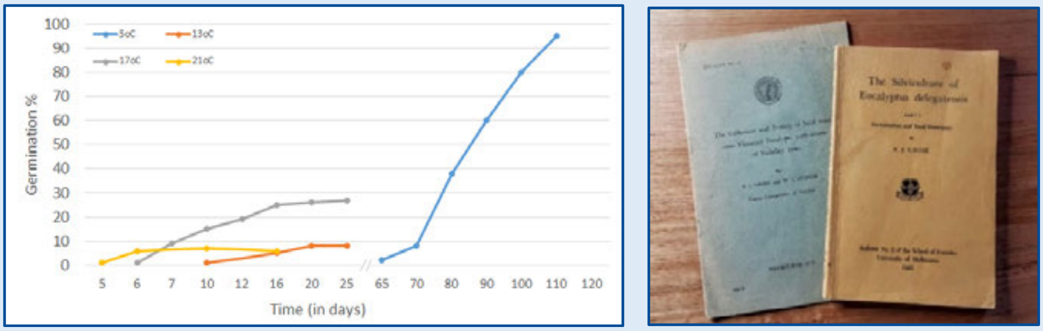

Figure 67. Germination percent (%) of Alpine Ash seed samples tested by R. Grose at various temperatures, initially indicating that a long period of cold incubation (5°C) eventually produced a high germination percent. This is the pioneering work on dormancy in Alpine Ash (Grose 1963).

As indicated by Grose's early work, there are exceptions within the seed population, with a percentage of non-dormant seeds having the capacity to germinate in autumn (Grose 1963). This proportion varies between seed-lots, is usually small, but could account for up to 60% of seeds, and was referred to by Grose as degree of dormancy.

Although most dormancy research has taken place in laboratories, field measurements or observations can also reveal the dormancy characteristics of Alpine Ash seed developed at a particular site. For example, after the 2009 Black Saturday bushfires near Cambarville, a cohort of the Alpine Ash seed, which had been induced to fall in large quantities by the fire, germinated in autumn (Bassett 2009a). They were numerous and developed to at least the first-leaf stage prior to winter (**Figure 68**). They were not individually tracked, so their fate is uncertain. However, larger multi-leafed seedlings were found in the same area in the following spring and were assumed to be from that autumn cohort. This suggests that not all autumn-germinated Alpine Ash seedlings were killed by the winter conditions of 2009, particularly given Camberville is located in the 'milder' low elevation zone for Alpine Ash. It is feasible that autumn seedlings, when surviving into spring as larger individuals at lower elevation sites, become dominant in regrowth throughout the proceeding summer. This occurred in a study of the Tasmanian sub-species on milder sites where autumn germinants survived winter to become the dominant cohort in the following summer (Battaglia 1996).

Grose explored the impact of various environmental variables on strength of dormancy, including geographic location, forest stand level, aspect and elevation, different seed crop ages, parent tree, seed colour and seed size. Only one variable had negative significance, that being seed size, while all other variables expressed no impact on strength of dormancy. The similarity between seed on different elevations, seed crop ages (which includes colour, see **Figures 59-61**) and different locations/stands, indicated a 'remarkably high level of heredity', with dormancy being more genetically controlled.

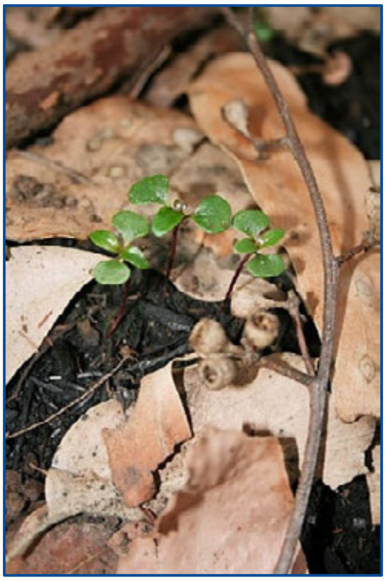

Figure 68. Alpine Ash germinants photographed on the 25th May 2009 following the Black Saturday bushfires. Their seeds were not dormant, with an estimated date of emergence in early April.

It is fascinating that elevation was found to have little impact on strength of dormancy. Furthermore, Pederick (1986) in his 1980 trials found that germination percent, germinative energy and degree of dormancy were not related to altitude of seed source, indicating that even an autumn cohort could germinate at higher elevation provenances.

However, if autumn germination does occur at higher elevations, it is expected that autumn germinants would be more susceptible to the more extreme winter conditions at such elevations, as was the case in Battaglia's 1996 Tasmanian study, at which time the higher elevation spring cohort in his study became the dominant cohort in the following summer, due to the loss of autumn germinants over winter.

Seed size, however, impacted the degree of dormancy within a seedlot. In Grose's study, *larger seeds expressed a higher capacity to germinate without stratification*, with overall higher germination percents in untreated larger-size cohorts. In general, for eucalypts, larger seeds are known to perform with better vigour in the field, although Close & Wilson (2002) found little variation by seed size for Alpine Ash in their study, perhaps masked by the influence of stratification generally across all seed size classes. Regardless, coupled with these characteristics for Alpine Ash and other eucalypt species (Bassett 2011), the evidence indicates that larger seeds are the most valuable within a seed-lot, requiring specific protection. For example, when cleaning extracted seed, an appropriate sieve size must be used to minimise the quantity of larger seeds being caught and inadvertently discarded from the sieve that separates extraneous matter.

4.3.2. Stratification of dormant Alpine Ash seed

Dormancy in Alpine Ash seed must be broken by 'stratification' to allow germination, and it is the cold temperatures and moisture typical of winter that provides the stratifying combination, allowing germination to eventually take place when warmer weather arrives in spring (Grose 1963; see also Bassett 2011, being NFSG No 1). Grose (1963) also refers to the stratification process as 'after ripening', but that term is no longer preferred. Cold temperatures alone will not break dormancy of seed released from capsules din its relatively dry form. Rather, a high moisture content is required, so seeds must first be imbibed.

Grose (1957; 1963) confirmed both the optimal temperatures required for stratification and for rapid germination; those being 4-5^{o}C and approximately 20^{o}C respectively. The original research (**Box 13**) had alluded to these temperatures (the 17^{o}c and 5^{o}C charts, **Figure 67**), but further extensive tests, both in the field and laboratory, were required to identify the most favourable temperatures. Stratification occurs over time, and Grose's original laboratory experiments indicate an optimum of 4-6 weeks. However, routine testing of collected seed-lots in Victoria indicate that a further 2 weeks is often needed to achieve acceptable germination percents (>80%), depending on provenance. Refer to DSE (2011)[43] for the most recent seed testing instruction, which recommends a standard 8-week period for stratification when testing Alpine Ash seed.

This longer stratification accounts for the variation of strength of dormancy present in all seed lots (see **Section 4.3.1**). For example, seed size influences strength of dormancy, which is weaker in larger seeds, meaning a shorter stratification is required to break dormancy. This enables germination to occur earlier in larger seeds and with a higher degree of germination energy (also known as 'vigour')[44] than for smaller seeds (Grose 1963). In Grose's study, smaller seeds germinated later, after longer stratification, presumably due to their lower vigour and need for additional protection given their higher level of susceptibility to winter conditions.

[43] Seed testing instruction for the State's Laverton facility, produced by Forest Solutions
[44] Germinative energy (vigour) is indicated during seed testing by analysing the speed of germination.

Germination energy also increases following stratification, to the extent that seeds will eventually germinate even at 4-5°C if left in stratification for 10 weeks. Grose knew about this, and tests undertaken at the Laverton North seed testing facility during 2022 again demonstrated this when stratifying seeds in petri-dishes were inadvertently left in cold conditions for 10 weeks instead of eight (**Figure 69**). It is unknown if this occurs in the field during long winters, and the fate of such germinants may be questionable.

Figure 69. Alpine Ash seed just after laboratory stratification for 10 weeks, germinating at 4°C. Note the white, hairy root radicles emerging from seeds.

Artificially sown Alpine Ash seed must first over-winter to allow for stratification, dictating the need to ideally sow prior to close June, but no later than mid-July in colder years. Although sowing could begin in autumn, since most natural seedfall occurs then (see **Section 4.1.3**), winter sowing is recommended to maximise the spring-only cohort.

4.3.3. Other dormancy characteristics

Two other characteristics of seed dormancy in Alpine Ash are worthy of highlighting, given their potential impact on the breaking of dormancy, and ability to impact silvicultural outcomes following artificial sowing. These are:

(1) Primary dormancy, already present, can be further strengthened, and

(2) A secondary dormancy can be induced following stratification.

(1) Strengthened primary dormancy

Primary dormancy can be strengthened further in seed already dormant if seed is incorrectly stored or following sowing in the field (see Grose 1963). Storing seed in relative humidity conditions >40% at temperatures 15°C or above will strengthen primary dormancy, requiring a longer stratification period once sown. This can reduce the probability of Alpine Ash seed successfully germinating during seasons with mild, dryer winters, such as occurred during 2007. In recent times, this is perhaps less of an issue given eucalypt seed is now routinely stored at 4-5°C and low humidity conditions in Victoria.

For seed naturally falling in autumn or induced to fall in summer following a bushfire, dormancy can be strengthened if subject to moist conditions while temperatures are still mild to warm; that is, unfavourable for stratification or germination. Longer cold periods would be required during winter to break stronger dormancy, and this may become an issue if a changing climate increases the frequency of dryer, milder winters with shorter snow periods similar to what occurred in winter 2007. This is good reason alone not to intentionally sow Alpine Ash seed prior to winter.

(2) Induced secondary dormancy

If temperatures become unfavourable during the period of, or after, stratification, seeds can return to a dormant state with a ‘secondary dormancy’ induced. The strength of this secondary dormancy will depend on the period that seed is exposed to the unfavourable temperatures. It could be equal to, less than, or greater than the original dormancy. Another period of stratification is needed to break secondary dormancy.

Secondary dormancy could have been one issue related to the difficulties with forest recovery following the 2006/07 Great Divide fire. Fagg *et al.* (2013) suspected, amongst several possible issues, poor stratification due to mild winter conditions (**Box 11**), but a secondary dormancy induced by unfavourable temperatures on seeds that may have been successfully stratified could also explain failure to germinate in the spring of 2007. It is unknown if any ungerminated seeds survived in a dormant state to germinate in the second spring of 2008, known as ‘protracted recruitment’ (see **page 84**).

4.3.4. The germination process

Once dormancy is broken, germination of Alpine Ash seed requires an ideal temperature in the range 17-25^{o}C and a fully imbibed moisture content, with higher temperatures having a drying effect and risking an induction of secondary dormancy. As indicated in section 4.3.2, germination can begin if maintained at colder temperatures for greater than 8 weeks, but the health of developing germinants would likely be at risk if air temperatures did not rise. Temperatures lower than 17^{o}C will produce a lower germination % (Grose 1963).

In the laboratory, during seed testing, the first sign of germination is the emergence of a hairy root radicle near the hilum, through a split in the seed coat (**Figure 69**). This begins within the first 4 days but is usually longer in the field. Geotropism takes effect once the radicle and root collar separates from the seed coat in its entirety and the hypocotyl extends upwards, raising the cotyledons while still folded and encapsulated in the seed coat. The seed coat is eventually shed as cotyledons begin to unfold. Germination is considered complete once cotyledons assume their final shape. Cotyledons differ from leaves, which come later, and are kidney-shaped with entire margins. Usually there are only two cotyledons, but three can rarely appear from a large seed (**Figure 70**).

Germination energy (seed vitality) in Alpine Ash is magnified following stratification, speeding up the process of germination relative to other species germinating in autumn. During the testing of 26 Alpine Ash seed-lots in March 2022 at the Laverton North seed testing facility, collected from Erica, Mansfield and Swifts Creek districts, an average of 89% (range 69-99% by replicate) of all viable seed had completed germination within 7 days. The equivalent stage of germination in Mountain Ash, for which stratification is not usually undertaken, takes 14-18 days (DSE 2011; Flint & Fagg 2007). This is likely another characteristic typical of a high elevation specialist, moving individual plants out of early vulnerable stages sooner, contributing to survival and establishment.

Figure 70. (Left) An Alpine Ash germinant at the cotyledon stage, having recently emerged from its seed coat near Mt Hotham, 2013. **(Right)** Rarely seen, three cotyledons can sometimes present, with this 'good-luck' 3-cot germinant found on Connors Plains during October 2010.

In the field, the actual process of germination may take a longer period of time compared to laboratory conditions (**Figure 71**), depending on the interplay of varying daily temperatures and moisture conditions. The proportion of seeds quickly germinating once ideal temperature arrive in spring will vary. In some cases, the proportion not germinating may be unacceptably high, impacting species performance. For example, during the extended millennial drought period (**Figure 55**), snowfall in the winter of 2007 was very poor throughout Victoria's high country. Conditions were so mild that Fagg *et al.* (2013) suspected stratification was incomplete, and dormancy maintained in a high proportion of seed, whether sown or naturally disseminated (see **Box 11**). Germination proved poor in places, leading to the patchy recovery of Alpine Ash forests, with some localised regeneration failure in both treated salvaged and untreated non-salvaged areas (see **Box 14, Chapter 7**).

What becomes of dormant seed not germinating in the first spring and remaining in soil has not been well studied. Unlike its cousin, Mountain Ash, some portion of seed of Alpine Ash may remain live in the soil for up to two seasons, resulting in a '*protracted recruitment*'.

Grose (1960b) did not support this.[45], claiming that soil-borne seed will only be available to regeneration for a few months after it has fallen, and effectively 'confining' germination to the first spring.

[45] Interestingly, Needham (1960), referred to in Cremer *et al.* (1978), reported a similar capacity for Alpine Ash, but his observation was rejected by Grose based on research reported in the same year of 1960. But our silvicultural knowledge of Alpine Ash has developed further since Grose was active in the 1960s and 1970s, indicating there was some credit to Needham's observations and that the silvical characteristics of the species have indeed proven more complex than earlier thought.

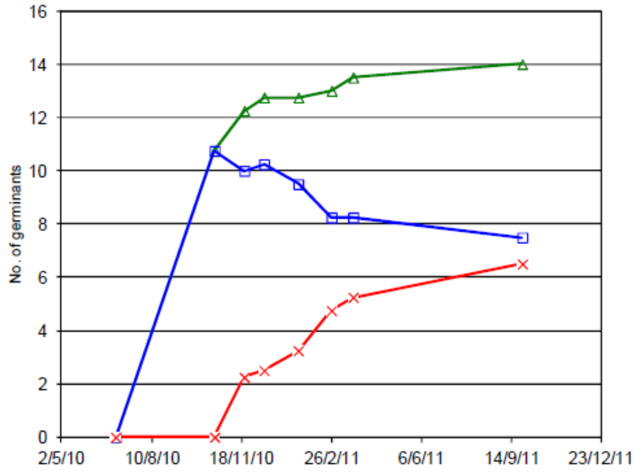

Figure 71. Alpine Ash germination process extending into a second Spring since July 2010 seeding on Morris Track North, Connors Plains, showing Total germination (∆), survival (☐), and mortality (x) (Bassett *et al.* 2012).

However, protracted germination for at least a proportion of seeds has been reported in Victoria while monitoring post-harvest regeneration (Bassett & White 2003; Fagg *et al.* 2008). In fact, re-treatment of understocked areas following first attempt regeneration in Victoria can be routinely delayed for a further year in case there is protracted germination beyond the first spring.

This capacity of Alpine Ash was clearly captured during second-attempt regeneration of salvage harvested areas on Connors Plains following the 2006/07 bushfire (**Box 14, Chapter 7**), when an average of 15% of established Alpine Ash seedlings were recorded to have germinated late summer into next autumn, including a small component in the second spring in 2011 following winter 2010 sowing (**Figure 71**). Such protracted recruitment in this operation was most obvious on soil disturbed, grey clay loams, compared with red duplex soils (18% of germinants; Bassett *et al.* 2012).

4.4 Seedling establishment and survival

Germinants have a chance to survive and grow into established 'seedlings' if the root radicle finds a good depth of mineral soil within days of emerging. Following dissemination, seeds can come to rest in many unfavourable niches, including shallow soil, root balls of fallen trees, into deep litter, or onto hard-baked ground unreceptive to seed. Ideal seedbed conditions include an ash bed overlying deep soils, or disturbed mineral soil with a friable top-soil layer. It is ideal for seed to penetrate the top 1-5 mm of ash/friable soil layer.

If the niche is conducive, fine roots will develop and extend into soil to find moisture, and these can be typically 3-10 cm long and multi-branched while still at the cotyledon stage. The first pair of leaves appear on surviving germinants at the confluence of cotyledon axils within the first four weeks, and by late summer, established germinants have developed multiple leaves. Seedlings are established with mature leaves by next autumn in the calendar year after seeding or seedfall (**Figure 72**).

Figure 72. Alpine Ash seedling development near Mt Hotham following reseeding for forest recovery after the 2013 Harrietville-Alpine Bushfire. **(Left)** A 2-leaf germinant 28th October 2013. Note the cotyledons still present; **(centre)** A Multi-leaf germinant 3rd January 2014; and **(right)** an established seedling of 30 cm height with mature leaves 31 March 2014.

4.4.1. Factors affecting establishment and survival

Some factors impacting the success of Alpine Ash seedling establishment have already been presented, such as the fate of seed once disseminated or sown onto seedbed (**Section 4.1.3**), dormancy, time of sowing or seedfall on stratification, and germination patterns (**Section 4.3**). Other factors which have major influence include seedbed type and niche, frost impacts, fungal attack, competition from other vegetation, and the impact of browsing animals.

Seedbed effects

Seedbed quality is one of the most critical factors influencing establishment. Unless the roots of a germinant can penetrate into mineral soil, the germinant will perish. The most important 'site preparation' outcome for regeneration success is to remove the litter layer. Litter can be thick and form a 'matted', impenetrable 'duff layer'. It is true that germination of non-dormant or stratified seeds can occur wherever moisture and temperature are ideal, even if not suitable for establishment. For example, seeds can germinate on thick matted litter, and also on logs, on tree fern stems, in rock fissures, on metalled roads, to name a few niches; but all are expected to die from lack of root penetration into soils. One author (O. Bassett) carefully excavated the roots of a dead Alpine Ash germinant in deep litter and found 148 mm of branched root growth; no doubt probing through litter in a failed attempt to find mineral soil and its water holding capacity. The germinant was found desiccated.

In contrast, a superior seedbed is friable mineral soil, free of litter, onto which seed has been artificially sown or naturally fallen. An overlying ash bed from fire can further enhance this (Grose 1957; Stoneman 1994). Fire itself removes the litter layer, including high intensity slash-burns during operations to regenerate Alpine Ash (Ritchie 1975), and the resulting ash bed provides additional niches, can enhance seedbed temperature and retain warmth for longer because of its black colour, and can increase nutrition; particularly the quantity of available phosphorous (Grose 1957; Attiwill &

Leeper 1987; Campbell & Bray 1987; Florence 1996). This additional nutrition is known to enhance early growth rates and reduce mortality in establishing Alpine Ash (Grose 1957; Lutze & Geary 1998), and this has been frequently demonstrated when monitoring germination and early establishment during the decade 2010 to 2020 (Bassett *et al.* 2012; Bassett *et al.* 2015; FS 2017).

Seed harvesting by ants and other insects, such as lygaeid bugs, is a related and significant issue. Depending on ant/insect population size, shed seed may be entirely harvested by ants and taken underground into their nests (Grose 1957; Stoneman 1994). However, satiation by large seedfall events after a bushfire usually ensures sufficient seeds remain for forest recovery (O'Dowd & Gill 1984). Even still, ants prefer to carry larger seeds (Stoneman 1994), leaving the smaller seeds with lower vitality.

Although slash-burning is likely the best seedbed preparation technique, because it removes litter and creates an ash bed (Florence 1996; Lutze & Geary 1998), careful mechanical disturbance of soil can also produce suitable seedbed conditions. Establishment and growth of Alpine Ash will be more variable on disturbed soils, depending on soil type which can change over small distances (Bassett *et al.* 2012). Soil type influences nutrition, the rate at which competing colonisers grow, susceptibility to frost heave, and the rate of desiccation between rain events; all influencing establishment success (Stoneman 1994).

Frosting and frost-heave damage

Grose estimate that 150-200 frosts occur annually in Victoria's Alpine Ash zone. It is winter frosting of leaves and frost heave which produce the most mortality of autumn germinants from non-dormant seeds. Grose (1957) and Battaglia (1996) found up to total decimation of autumn germinants at higher elevations, with the spring cohort dominating established seedlings. Snow deaths of germinants and seedlings occur due to prolonged saturation in water cycled in situ from snow melting during 'warmer' daylight hours. Frost heave literally heaves germinants from the ground, either leaving them prostrate and uprooted when frost melts, or stem broken as ice grows upwards (**Figure 73**).

The impact of frosts in spring usually depend on season. Drought periods with many cold nights at freezing point and clear of cloud are the worst years. This occurred in 2007 following the 2006/07 Great Divide fire. Limited regrowth due to poor seed crops and reduced sowing rates were impacted by severe spring frosts and other factors, causing widespread mortality (Fagg *et al.* 2013; Bassett *et al.* 2012; see also **Box 14, Chapter 7**).

However, being a high elevation specialist, with adaptations like dormancy influencing time of germination, Alpine Ash is more tolerant of frost conditions than its lower elevation cousin, Mountain Ash (Grose 1963; Florence 1996). Dormancy largely excludes autumn and winter germination, avoiding deep snow conditions that are known to kill Alpine Ash seedlings (Grose 1963; Battaglia 1996; Florence 1996; Bassett *et al.* 2012). Unlike for Mountain Ash, Pederick (1986) found little genetic basis for variation in frost resistance with elevation for Alpine Ash. Practically, this means that artificial seed movements during regeneration operations can occur across a range of elevations; seed transfer limitations being <u>not</u> so critical in this species.

Figure 73. (Left) a frosted germinant lies prostrate; uprooted by growing columns of frost. Red/white arrows indicate the lay of the root. **(Right)** A germinant snapped off along its stem by columns of upward frost heave, given the roots did not dislodge. Note the columns of ice. These images are of Mountain Ash frost damage, but it occurs in the same way for Alpine Ash. Both germinants died.

Drought and desiccation

Over the two decades prior to 2020, drought was a major component of Victoria's climate (**Figure 54, Section 4.1.2**). The years 2010 and 2016 are the only 'wet years' experienced prior to mid-2020 in this period. The millennial drought lasted 12 years (1997 to 2009 inclusive), with mini droughts occurring frequently since 2010. Given droughts and bushfire are inextricably linked, this has had serious implications for Alpine Ash forests, resulting in large areas of regrowth vulnerable to future fires (See **Chapters 3 & 7**).

Dry periods are problematic to germination and establishment. If germination occurs successfully, then a lack of adequate rainfall during the first spring and summer can desiccate topsoils and kill Alpine Ash germinants. Some desiccation over every summer is normal, accounting for up to 50% germination death, and is listed as one cause of mortality in many monitoring programs (Grose 1957; Battaglia 1996; Bassett *et al.* 2012; Fagg *et al.* 2013; Bassett *et al.* 2015; FS 2017; Singh *et al.* 2021). Mortality beyond 50% by desiccation is likely due to drought, which indicates problems during regeneration or forest recovery operations.

However, Alpine Ash can adapt to and exploit the high elevation environment to survive dry conditions. For example, **Figure 74** shows two germinants photographed on the same day about 11 months after the 2013 Harrietville-Alpine bushfire. One seedling was just below a ridge where fog-drip and condensation contributed moisture. The other was slightly down slope, out of the fog-zone, with limited available moisture. Leaves had moved inward to reduce radiation interception and moisture loss from stomata (Stoneman 1994). Both mechanisms of drought resistance increase resilience in eucalypts during dry conditions.

Competition from other vegetation

For Alpine Ash establishing in spring, competition from native vegetation has the greatest impact than any other factor. However, competition is not mutually exclusive, interacting with dryness, soil type and seedbed condition to potentially increase competition affects by the deficit of available water (Stoneman 1994).

Snow Grass (*Poa spp.*) has proven to generally exert the most severe impact on germinating Alpine Ash, reducing soil moisture by forming close-knit swards of grass. Grose (1957) found in his 1954/55 study that grassy seedbeds produced the shortest seedlings at age 10 months, and the highest mortality by 14 months after sowing, irrespective of conditions.

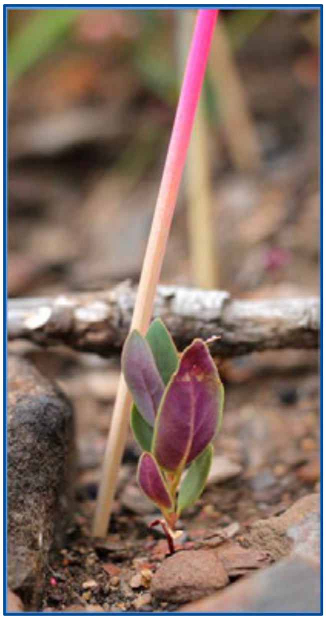

Figure 74. (Left) A stressed Alpine Ash seedling at 2:05 PM on the 20th January 2014 during a dry summer period near Mt Hotham. Leaves curl upward to reduce moisture loss. **(Right)** A separate germinant, image taken 15 minutes later upslope in the fog-zone. Condensation, and fog-drip off a dead mature Ash tree, was keeping this seedling healthy and alive (Bassett & Pryor 2014).

In a study of Alpine Ash establishment on Connors Plains, Bassett *et al.* (2012) also found recovering Snow Grass to provide the greatest competition and produced the highest mortality rates and lowest early growth rates. The study site and design accounted for two main soil types and four understorey vegetation types. Study coupes were mechanically disturbed to create seed beds receptive to seed. Grasses were sprayed with herbicide during site preparation, but recovered rapidly. Seed was sown in the winter of 2010 and germination monitored until the second spring in 2011. **Figure 75** summarise the results for Ash mortality and early height growth.

The lower mortality of Alpine Ash under Bracken, found in the Connors Plains study, is an interesting result (**Figure 75**), and supports one author's long-term observation that bracken can act as a form of shelter to establishing Alpine Ash seedlings, perhaps offsetting moisture deficits by shading to reduce transpiration. Alpine Ash seedlings can remain alive under bracken for several years, then rapidly grow through bracken from a stunted state when conditions allow, up to age 6 years[46].

[46] O. Bassett observation. Also observed by multiple State-employed Forest Officers over 30 years.

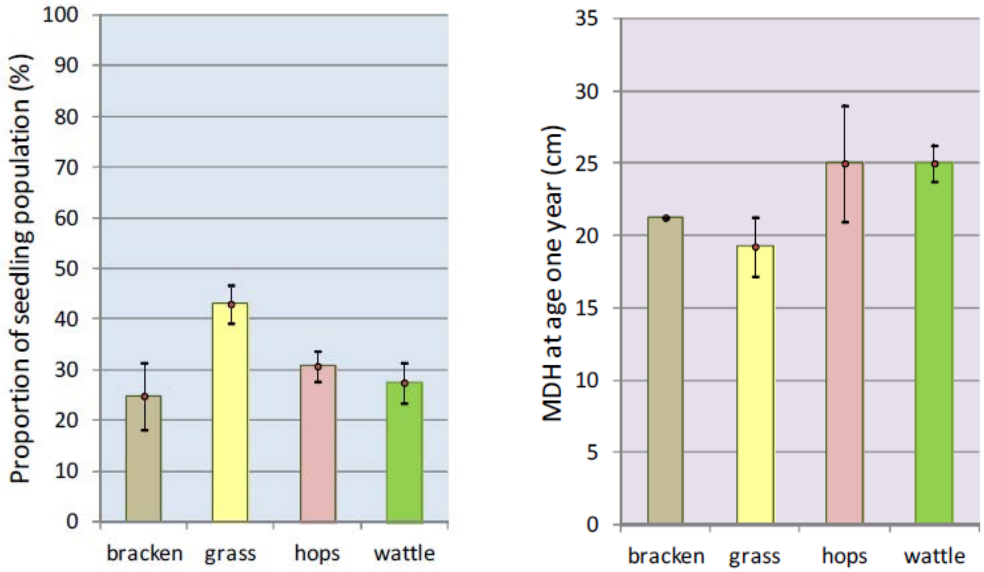

Figure 75. (Left) Mortality of Alpine Ash at 12 months by predominant understorey species prior to site preparation. **(Right)** Same but for mean dominant height (MDH). Plot count (n) is 60 across 12 coupes, replicated for soil and vegetation type (Bassett *et al.* 2012). Note: 'grass' = Snow Grass (*Poa spp*.)

Another study of germination and survival occurred after the 2013 Harrietville-Alpine fire, which found grassy sites to be the only environmental factor correlating negatively with seedling density in the first spring following the bushfire. A mix of environmental factors were tested comparing competition between various understorey species, and testing the influence of rock, litter, ground herbs (non-grass), bare soil and coarse woody debris (Bassett & Pryor 2014; Bassett *et al.* 2015).

Otherwise, Alpine Ash competes well with other rapidly colonising species such as *Goodenia ovata* (Hops Goodenia) and various wattle species such as *Acacia obliquinervia* (Mountain Hickory Wattle), as long as the timing of germination from seed, or planting of seedlings, occurs either earlier or close to the same time as germination of these other species. See **Chapter 7** for special measures to deal with competition when planting seedlings into already established vegetation during infill planting operations.

Fungal attack

Like all eucalypts, Alpine Ash germinants and seedlings are susceptible to 'dampening-off' due to antagonistic fungal infection (Grose 1957). Although the source of infection can be the seed itself (Drake 1974), most pathogens are soil borne, such as *Pythium* and *Fusarium* species (Stoneman 1994). The severity of fungal growth in the vicinity of germinants seems to be influenced by seedbed, moisture, and the level of shading by competing vegetation (Cunningham 1960). This latter is because direct sunlight can 'solarize' soil resulting in sterilisation and the removal of antagonistic fungi (Ashton & Willis 1982).

Soil can be also sterilized by fire, producing an overlying ash bed temporarily free of antagonistic fungi and richer in Phosphorous (Mwanza & Kellas 1987). Although disturbed soils can create suitable seedbed for Alpine Ash, with some solarisation possible, slash-burning for regeneration creates the best seedbeds for establishment and growth.

Dampening-off has been a commonly recorded source of mortality of Alpine Ash germinants within their first 12 months during most germination monitoring programs in Victoria (Bassett *et al.* 2012; Bassett *et al.* 2015; FS 2017).

Browsing animals

Browsing or trampling of germinants and seedlings by native animals such as Swamp Wallaby and introduced Rabbits, Deer and high-country cattle is possible within the first 12 months following site establishment. However, Statewide surveys of browsing undertaken by the State government in Alpine Ash found browsing damage levels to be only moderate or minor following regeneration surveys on timber harvesting coupes, where site establishment was by aerial sowing or seed fall from seed trees (Wallace & Fagg 1999; Sebire 2001; Di Stefano *et al.* 2009). These damage levels had little impact on regeneration.

Seedlings planted during reforestation are at higher risk, and some protection is recommended, such as use of tree guards (Bassett *et al.* 2010) or application of WR-1 browser repellent as 'gritty seedlings' (Marks *et al.* 1995; Fagg 2002). The latter was applied to Alpine Ash nursery-raised seedlings prior to planting by VicForests during the Connors Plains reforestation project. High-country cattle were known to be in the area post 2006/07 bushfire but had little impact. It's unknown to what level the repellent contributed to this outcome, with most of the mild damage caused by trampling (Bassett *et al.* 2012).

4.5 Stand Development

Compared to Mountain Ash, the growth and development of established Alpine Ash seedlings into a mature forest stand is not well documented. Both species develop into the 'tall-open forest' habit described by Specht *et al.* (1974), and the general ecology and structure of Alpine Ash forests are described in **Chapter 3**.

Research by Dr. David Ashton, summarised in Flint & Fagg (2007) and Florence (1996), describes stand development for Mountain Ash, which generally represents the various growth stages for Alpine Ash. However, the latter is situated at higher elevation and often lower quality sites, dictating a shorter annual growth window with smaller upper limits to height and bole diameter (dbhob); although the latter dimension can be comparable to Mountain Ash for over-mature individuals on well-drained, nutritious sites.

Table 8 is adapted from Ashton (1975b), showing the 'seven arbitrary growth stages' also typical to Alpine Ash. **Figure 76** visually represents its early stand development at Granite Flat, North East Victoria. As seedlings establish and develop, multiple branches appear within the first year, with axillary branch development accelerating in the second year. At this stage, perhaps three of these branches compete for apical dominance. At the same time, a tap-root develops, providing early stability. Note that the dominance of this tap-root declines through to pole stage, with priority given to complex lateral root development for stability of later tall-forest dimensions (Table 8). Buttressing, which incorporates these lateral roots, will eventually develop once mature, providing added stability (Florence 1996).

Table 8. Growth stages during stand development of Alpine Ash by indicative age. Adapted from Ashton's (1975b) Mountain Ash data. Diameter is at breast height over bark from sapling stage. The 'stems/ha' for Mature (200) is the Ecological Vegetation Community (EVC) benchmark for wet forests.

Growth stage	Height (m)	Diameter (cm)	Age range years)	Comments
Seedling	<2	<2	up to 2	4% of viable seed
Thicket	2-6	2-3	2-4	3,000 stems/ha
Sapling	7-12	4-10	4-8	2,000 stems/ha
Pole	13-30	12-40	10-30	Reproductive maturity
Spar	30-40	50-90	30-80	'Open' canopy (e.g., 1939)
Mature	40-80	90-200	80-200	200-250 stems/ha
Over-mature	30-50	250-600	200-300	20-50 stems/ha

Figure 76. Alpine Ash regrowth development to thicket stage **(Table 8)** at 4 years **(top)**, following salvage harvesting at Granite Flat in 2003 to dense seedling stocking at age 1 year **(lower image)**. Heights at age 4 years were typically 3-5 m.

(Image sequence: Dave Sayce, DEECA).

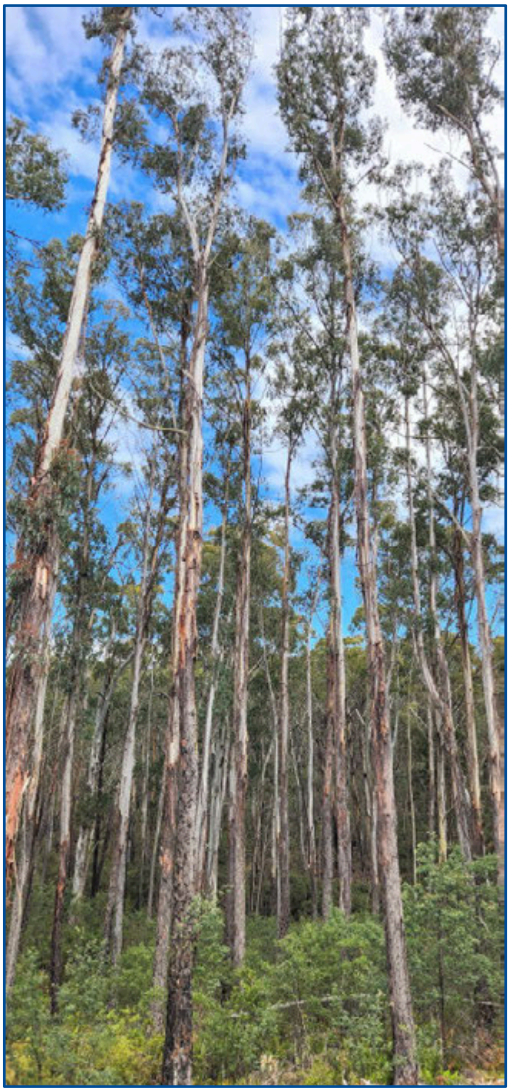

Figure 77. A Pole to Spar stage Alpine Ash regrowth forest on Mt. Timbertop, near Mansfield, photographed in 2023.

Crown development in Alpine Ash follows a similar sequence to Mountain Ash (Ashton 1975a, 1975b), with maximum canopy cover occurring within the spar stage. Understorey can be quite sparse during the sapling into spar stages. However, as growth proceeds from pole stage (**Figure 77**) to maturity (**Figure 1** in **Chapter 1**), the canopy becomes more 'open', with projection typically covering only 35-55% of the forest floor (**Figure 78**).

As the stem/bole size grows larger in eucalypts, demand for growth capacity increases, stimulating a proportional growth of branch biomass for greater photosynthetic production (Attiwill 1962). This relationship was first demonstrated for Alpine Ash by Bassett (2009b), following the 2006/07 bushfires, when developing crown size regression models to support strategic seed crop assessments of older-age regrowth and mature forests[47]. The original regression model was later refined by Lutze and Bassett (2020) to also account for the growth stages of immature Alpine Ash.

What is remarkable is that various crown variables, such as leaf area, branch biomass or branch counts by size-class, of all Alpine Ash trees in any given stand can be explained by a single mathematical model.

This relationship of bole to crown size variable being dictated by forest age, stand dynamics and growth parameters.

Mortality of suppressed stems occurs naturally throughout all stages but peaks in early stages due to intense competition (Fagg 1981; Attiwill & Leeper 1987; Bassett 2001), enabling 'self-thinning' to occur, with site resources concentrated onto fewer stems and growth rates accelerating into pole stage (Burgman *et al.* 1994).

Height and diameter growth varies between Alpine Ash stands in Victoria, depending on site quality; usually influenced by soil type, elevation, slope, drainage, and exposure

[47] Needed to assess the capacity of fire-killed Ash forests' to naturally recover (see **Chapters 4 and 7**)

levels. Vegetation assemblages reflect these site qualities, with grassy areas producing the slower growth rates, even beyond thicket stage (Keenan & Candy 1983). Productivity estimates for the species during stand development are few, but Turner *et al.* (2011) reports unthinned mean annual increments of 10 to 12.7 m^3/ha/yr, with typical standing wood volumes of about 7-800 m^3/ha at age 60 years for Ash forests of good site quality.

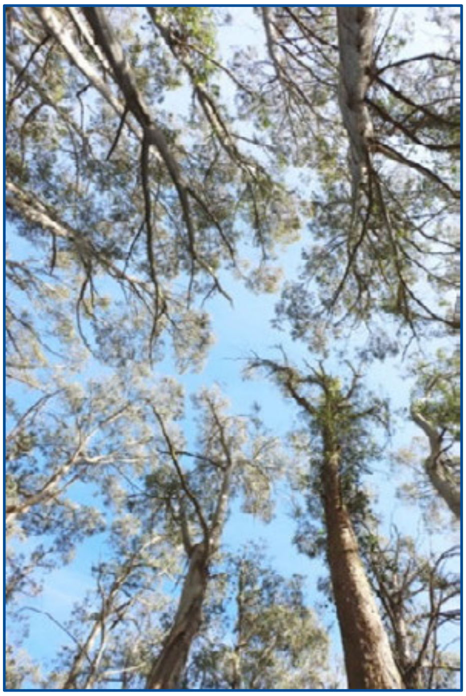

Figure 78. (Above) Alpine Ash Spar stage forest at Mount Wills in 2022, showing a range of diameters that reflect various dominance classes in the stand.

The vertical Image **(at left)** shows canopy development and 'openness' from the same location. The species is 'crown shy' and branches from neighbouring trees do not interlace.

Alpine Ash in Victoria usually develops even-aged stands following major disturbances but can develop multi-age structures depending on local fire history (Grose 1960b; Campbell *et al.* 1984). See **Chapter 3** for discussion of forest ecology, structures, and age classes.

5. Development of Silvicultural Systems in Alpine Ash

Silviculture is the science-based practice of modifying forest composition, structure and/or function to achieve specific management objectives. In the past, silviculture enabled sustainable timber harvesting and the regeneration of the harvested areas to ensure forests were maintained and biodiversity conserved. This Chapter describes the silvicultural systems and practices that were used to achieve these outcomes in Alpine Ash forests.

5.1 Early development

The development of silvicultural systems suitable to Alpine Ash has followed the history of timber production in Victoria (**Section 2.2**). Alpine Ash forests were considered more remote than Mountain Ash forests which were utilised for timber prior to the Second World War. The impact of the 1939 bushfires caused a major dislocation of timber production. Timber was Salvage Harvested for 11 years after that fire, after which alternative sources of such high grade timber had to be found. A new roading program across the Great Dividing Range was undertaken to access the more remote Alpine Ash forests. Roads like the Tamboritha Road, which opened up the alpine region of Gippsland, were constructed to access Alpine Ash timber resources; the first logs being carted in 1961 (**Figure 79**). Regeneration after utilisation was priority, but it became quickly evident that the silvicultural characteristics of these forests were unknown, so research was undertaken (**Section 2.3**). The studies by Ron Grose were published, recommending the Seed Tree silvicultural system (Grose 1961). Early experience proved that seed trees were difficult to later recover, and were not a reliable source of seed. Seed collection and sowing were determined more reliable, so the preferred system switched to clear-felling, with seed trees only retained if sufficient seed was present.

Figure 79. Early log trucks hauling some of the first post-war Alpine Ash logs harvested from forests near Trapyard Hill, stopping at Licola for checking, having just been carted down the Tamboritha Road from the Bennison Plains Road in Gippsland.

(Image: circa 1968, FCV 1969).

At about the same time, Alpine Ash forests in New South Wales and Tasmania were also being accessed for timber. These stands were multi-aged and less suited to clear-felling. Instead, gap selection became the silvicultural system of choice in those States, given it takes advantage of the advanced regrowth already present in the multi-age structure. This system continues to be used in these States to harvest and regenerate Alpine Ash (**Section 5.4**).

For commercial purposes, clear-felling, with or without seed trees, was the most productive system in Victoria. In later years, the need to retain and encourage the development of large trees with hollows on Alpine Ash coupes, particularly for Leadbeater's Possum, drove the application of Variable Retention systems, designed to establish regrowth and protect larger retained habitat trees and other structurally diverse elements.

5.2 The historic role of strategic planning

Whether for historical timber harvesting, or for a revised 'active management' approach to forest management (**Chapter 6**), strategic planning for the selection of silvicultural systems and practices, requires clear definition of forest management objectives. The forest owner's intent is used to determine management objectives. These objectives are elaborated in policies, strategies, and Forest Management Plans. The current forest dynamic and silvics of eucalypt species are key knowledge that guides the selection of silvicultural system for tending forests, and this is detailed for Alpine Ash in **Chapter 4**. A mix of silvicultural systems and practices are then chosen to address the forest management objectives. Up until 2024, the three key objectives influencing choice of silviculture included timber production, water production, and biodiversity conservation. Other considerations were non-timber wood production, melliferous resources for apiary, and carbon sequestration.

During the era of timber production, the Code of Practice for Timber Production (DEECA 2022) ("The Code") required that sound planning consider the full range of forest values, in an attempt to manage State forests sustainably. Forest Management Plans sought to achieve the following:

- Provide for the perpetuation of native biodiversity;
- Maintain a diverse range of forest age classes and structures (**Figure 80**);
- Identify and mitigate impacts on historic places and Aboriginal cultural heritage;
- Minimise impact on water quality and quantity within any particular catchment;
- Minimise adverse visual impact in Landscape Sensitivity areas (**Figure 80**); and
- Facilitate effective regeneration of harvested forests.

There were two mandatory actions specified in The Code relating to silviculture, and the principles behind these remain relevant today wherever silviculture is applied:

(1) Silvicultural methods for harvesting timber must suit the ecological requirements of the forest type, taking into consideration the requirements of sensitive understorey species and local conditions; and

(2) The silvicultural system used to harvest timber must be recorded in a format that allows for future reference.

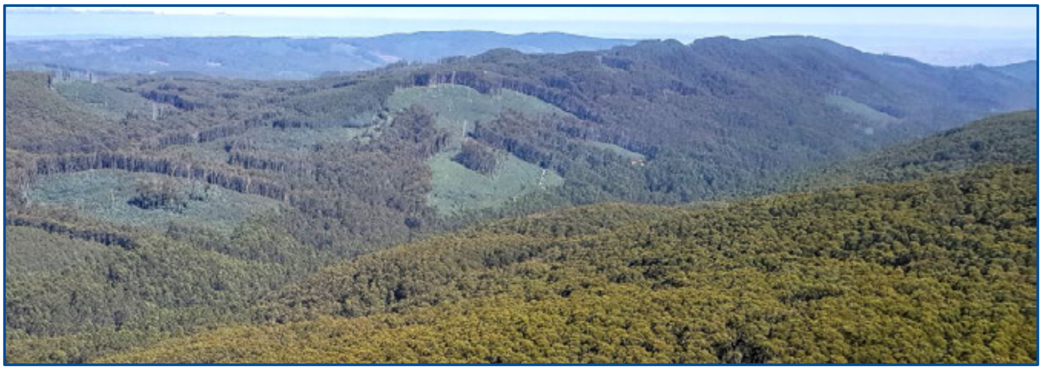

Figure 80. Airborne. A landscape with Alpine Ash in the Rubicon State Forest, within which harvesting has created a mosaic of age classes and structures. Note the retained habitat islands, connecting corridors and buffers, and areas of regeneration at various stages. The harvesting was also designed to minimise visual sky-line fragmentation of forest continuity.

There was also a mandatory action to identify biodiversity values at the planning stage of timber harvesting and address the risks to these values through management actions that included modifying silvicultural techniques and/or retaining specific structural attributes. Therefore, the selection of a silvicultural system that provided for adequate establishment, survival, and growth of young trees, while maintaining biodiversity of flora and fauna values, was key to complying with these actions.

Historically, in the case of timber harvesting, the choice of silvicultural system to use in Victoria was also bound by two other Standards:

(a) Sustainable forestry in Australia is defined in an Australian Standard, AS4708:2013. So for operations in Victoria, the Standard required that a Forest Management Plan describe and provide rationale for applied silvicultural regimes;

(b) In addition to the national standard, there is a stakeholder led standard set for Australia by the Forest Stewardship Council (FSC 2018). It had a requirement for Victoria that the forest manager use silvicultural practices that were ecologically appropriate for the vegetation, species, sites and management objectives.

Timber harvesting also occurred within a zoning system, with State forest areas partitioned into Special Protection Zones (SPZ), Special Management Zones (SMZ), and General Management Zones (GMZ). At the time of writing, these zones still exist. SPZs generally have special conservation values that were not compatible with timber harvesting. SMZs also have distinctive conservation or social values, but modified harvesting was previously permitted where it was compatible with those values. Here the selection of silvicultural systems needed to be adaptive and fulfil multiple objectives. GMZs were managed for the full range of conservation, social and economic values, including timber.

It is notable that Parks and reserves in Victoria are also zoned to identify priorities for management. Forests in public use zones may need active silvicultural treatment to make them safer or more aesthetic. Similarly, forests in conservation zones may require silvicultural treatment to enhance threatened species habitat or to achieve required composition, structure or forest function objectives.

5.3 Recent developments of silviculture in Alpine Ash

In the past, when selecting the most appropriate silvicultural system for utilising timber from Alpine Ash forest, the following considerations were made:

- The relative priority of different management objectives, such as wood production, water production, and flora and fauna conservation;
- Site factors such as slope, forest age, size class distribution, structure, and seed availability; and
- Commercial factors, such as availability of markets for the potential products, cost of access, supervision and regeneration, the availability of harvesting equipment and owner-experience, and safety considerations.

Forest managers needed a suite of silvicultural systems that allowed adaptive management, and which were holistic and nature based. Choice of silviculture depended on site and seasonal variations, and that choice impacted the success of forest regeneration. For example, a site prone to frost may require a silvicultural system that retains more canopy for shelter against exposure and radiant heat loss. Having a suite of options allowed forest managers to respond to changing community expectations and engage community participation with a broader range of available options (Jackson *et al.* 2021), a factor that today remains relevant to silviculture.

The silvicultural options for Alpine Ash are broadly based on the considerable research of Victorian silvicultural practices over the past 40 years. This research was both operational and experimental in the field. The Silvicultural Systems Project involved the establishment of a major research site in Mountain Ash (*Eucalyptus regnans*) forests near Tanjil Bren in the Central Highlands (CFTT 1997b). Although the planned Alpine Ash site was never established, learnings from the Mountain Ash research were used in commercial forest operations (VicForests 2019). The key learnings were: *(a)* although seedlings could be established under retained canopies, their survival and growth is poor; and *(b)* harvesting operations in small gaps can be unsafe and damaging to retained trees.

Silvicultural procedures in Victoria generally apply to Ash forests that include both Alpine and Mountain Ash stands. However, application of the procedures for Alpine Ash needs to consider the species-specific risks of frost, snowfall, seasonal access to coupes and the silvical need for Alpine Ash seed to stratify over winter to break dormancy (**Chapter 4**).

The range of silvicultural systems suitable for Alpine Ash forests are described in **Section 6.4**. There were five routine silvicultural systems used in Victoria to achieve regeneration following commercial timber production: clear felling and seed tree; two types of variable retention systems and selective harvesting, with variations within the group for harvesting intensity and the configuration of the gaps created. Thinning was not only designed to control the stocking and growth dynamics of stands to enhance timber production, but has also been used to enhance biodiversity and increase forest resilience to fire and drought (Keenan *et al.* 2021). A system of Salvage Harvesting was also available to utilise timber following major forest disturbances, like bushfire and windthrow events.

5.3.1 A brief overview of silviculture systems used in Alpine Ash

Clear-felling was the main system historically used to commercially harvest Alpine Ash timber from Victoria's State forests (Grose 1963, FCV 1972, Campbell *et al.* 1984; Fagg *et al.* 2008; VicForests 2019a). Variable Retention is a modern variation of clear-felling, designed to retain a range of structural elements present prior to harvesting to better manage biodiversity values (VicForests 2019a). Thinning is also important to tend and nurture selected forest growth and development parameters in support of a range of forest management objectives (Fagg 2006; Keenan *et al.* 2021).

Clear-felling system, including coupes with seed trees

- Clear-felling was most suited to uniform stands of Alpine Ash and, as determined in recent times, where there were relatively fewer habitat trees.
- Harvesting produced large spaces, within a maximum coupe size of about 25 ha, allowing high intensity broadcast slash-burning to efficiently create a seedbed (**Figure 81**). Future habitat trees were retained - up to 10 trees per hectare, and these could double as seed trees to reduce sowing rates, as seen at **Figure 81 left**.

Figure 81. (Left) Airborne: an active slash-burn on a clear-fell coupe with seed trees, Marysville district. **(Below)** A slash-burn following clear-felling in the Alexandra district during 2006 (below image: Caitlin Cruikshank).

- Benefits of clear-felling at the time included more efficient and safer coupe management, and better stand growth due to the absence of edge effects from retained patches that are more common in systems such as variable retention.

Variable Retention system

- Most suited to less uniform stands, or those coupes which had an older cohort, where such older forest elements are to be retained and younger trees recruited for future habitat, generally at densities greater than 25 trees per hectare (**Figure 82**).
- May comprise aggregated retention in the form of forest patches, or more dispersed retention to support multi-cohort stand development.
- Site preparation is generally via cooler broadcast slash-burning to protect retained elements, but some mechanical soil disturbance may be required.

- Benefits include improved habitat for arboreal animals and retention of some endangered species such as Tree Geebung.

Thinning systems

- Suited to young regrowth stands (aged 22 to 45 yrs) with a basal area of >35 m^2/ha.
- Removal of up to half the basal area of trees across the coupe, using the 'bays and outrows' system.
- Benefits of thinning include faster growth of the better quality retained trees as future sawlogs, with reduced harvesting rotations.
- Non-timber benefits of thinning include: increased water yield; increased resilience to fire due to reduced understorey, tree density and thicker bark development on retained trees; and development of larger habitat trees sooner with an accelerated rate of hollow development.

Figure 82. Airborne; a Variable Retention coupe showing retained overwood in patches and uniform distributions, plus other structural elements.
(Image: Mike Ryan, VicForests 2019).

These benefits are explored further in **Chapter 6**, regarding the application of modern active forest management techniques.

5.4 Comparison of Silvicultural Systems

There are a range of silvicultural systems suitable to Alpine Ash forests in Victoria, depending on the objectives of forest management for the area in question. The options are provided in **Table 9** and are listed against different management objectives that could be applied to Alpine Ash across all land tenures (**see also Chapter 6**). **Table 10** provides a comparison of systems that were available for timber harvesting.

Routine silvicultural systems for timber production

Single tree selection was not suitable for regeneration of Alpine Ash stands in Victoria because there was insufficient light at ground level for the germination and survival of seedlings. The system is also inefficient and had greater safety concerns.

Gap selection could be an effective system in Victoria, but only by ensuring sufficient canopy is removed to create the gap to allow the light penetration needed for regrowth establishment (**Figure 83**). This is managed by the layout and size of the gaps. It is also more successful in stands that are already multi-aged as a result of the history and intensity of previous disturbance events, such as harvesting and bushfire, or could be used in uniform forest to create structural diversity (**see Chapter 6**).

Table 9. Silvicultural systems that have been used in Alpine Ash forest, matched to the stand characteristics and forest management objectives in Victoria. The systems marked by an astrict* could remain relevant to modern active management practices across tenures (see Chapter 6).

Silvicultural System	Overall Stand Objective	Management Objective	Application
Thinning*	Control tree density and enhance timber production	• Obtain a commercially viable wood yield • Enhance growth on retained trees for future wood production	Multiple use forests where timber production is allowed
Thinning*	Control tree density for biodiversity and resilience objectives	• Increase the average tree size • Reduce the age at which trees mature and commence hollow development • Reduce stand competition to increase water yield, drought resistance, increase resilience to fire, and enhance understorey development	All forest tenures where these values are required
Full harvest Clear-fell, Variable Retention and Seed tree	Timber production, and establish a regrowth stand	• Obtain a commercially viable wood yield and • Retain existing habitat trees for current and future habitat value	Multiple use forests where timber production is allowed
Partial Harvest (Shelterwood, Gap Selection)	Timber production, and establish a regrowth stand	• Obtain a commercially viable wood yield and • Retain existing trees for future wood value	Multiple use forests where timber production is allowed
Partial Harvest* (Shelterwood, Gap Selection)	Establish a mixed age stand	• Increase stand structural diversity to improve habitat • Maintain continuous cover	All forests tenures where these values are required
Salvage harvesting*	Utilise timber or wood otherwise lost, and establish a regrowth stand	• Salvage timber to offset loss of sustainable yield (past objective) • Increase public safety • Remove fire-damaged or wind-thrown trees to allow regrowth establishment • Produce a supply of wood	Multiple use forests where timber production is allowed

Table 10. Silvicultural system options that were available for commercial timber harvesting and regeneration of Alpine Ash in State forests prior to 2024. Note that salvage harvesting is not comparable with other systems because it relates only to a damaged forest. Its alternative is to do nothing if circumstances are unsuitable. See also Thinning in **Table 9**.

Silvicultural System	Advantages	Disadvantages
Clear-fell	• Greater operator safety • Greater economic viability • Less competition for the regrowth from retained trees • More efficient site preparation operations • Road impacts are concentrated.	• Seed must be collected • Soil is exposed • Coupe is without a mature tree canopy for an extended period • Can impact on landscape values • Regrowth stands will reduce water yields from the coupe area.
Seed Tree	• Less seed needs to be collected • Seed trees add seed over an extended period • Some habitat value in seed trees • Can provide seed during future fire.	• Loss of timber products in seed trees • Requires a formal seed crop assessment.
Variable Retention	• Some mature canopy is retained for habitat and utilisation by fauna • Reduced landscape impacts • Greater structural diversity • Seed source from retained trees.	• More difficult site preparation operations • Greater risks to operator safety • Loss of wood products in retained trees.
Shelterwood	• Continuous cover providing greater protection from frost and cold air drainage; and • Overwood provides ongoing seed source and some habitat values.	• Damage to regrowth at second stage harvesting; and • Loss of growth in regrowth from overwood competition.
Gap Selection (not previously used, but now an option for active management (see **Chapter 6**)	• Harvesting operations can create a high proportion of the site preparation • Minimal landscape impacts • Repeated removal of the largest trees reduces competition and maintains site productivity • Creates or maintains a higher structural/age diversity than clear-fell • Can reduce reliance on collected seed.	• Repeated disturbances over time inside a coupe area equivalent to clear-fell; • Dispersed road impacts and higher access costs; and • Reduced timber yields per operation.
Salvage Harvesting (damaged forest)	• Salvaged timber offsets loss in sustainable yield • Provides a post-fire focus for integrating operations with post-fire recovery in IFKAR (**Chapter 7**) • Makes use of post-fire natural regeneration. • Reduces aerial hazards for post-fire working crews (OH&S).	• Can only use after a damage event • May produce a regeneration cost if natural regeneration is damaged • Ideally completed within 18 months, given timber will begin cracking and degrade • May draw-down seed stores.

Shelterwood was never successfully used in Victoria to regenerate stands following commercial harvesting, but appears to be a theoretical option based on the observations of stands that have been lightly burnt with a partial removal of the canopy, and establishment of some regrowth. Such a stand as this exists at the corner of Nunniong and Bentley Plains Roads, near Swifts Creek. In practice, these multi-aged Alpine Ash stands are rare in Victoria; being likely a quirk of fire-history, because they are more common in New South Wales.

Figure 83. Gap selection in an Alpine Ash forest near Tumbarumba, New South Wales (NSW), with established Ash regeneration from edge seed fall. NSW rarely uses Ash seed during silviculture. (Image: Caitlin Cruikshank).

Clear-fell silviculture remained one of two viable options for timber harvesting in Victoria's Alpine Ash, and was used on coupes where there are very few hollow bearing trees and more uniform canopy structures. Retaining future habitat trees on uniform coupes may have had only limited benefits for structural diversity over and above trees already present on coupe edges and buffers. For example, coupes dissected by many waterways with protective buffers had sufficient retained canopy in them, allowing the net area to be clear-felled.

Variable Retention (VR) operations became the other most common silvicultural operation in Alpine Ash forests in Victoria where the need for enhanced structural diversity was a priority.

Seed trees were not commonly used because the advantages of an ongoing seed source on-site was usually achieved in a clear-fell coupe by seed that may be present on habitat or VR trees that had to be retained by The Code and Management Prescriptions in Victoria.

The Salvage Harvesting silvicultural system

Salvage Harvesting was not an alternative system to the others listed in **Table 10**, but was an exclusive option following significant disturbances in forests over the age of 40 years to mature forests <120 years (Lawlor & Theobald 2005). In such cases where damage is caused, the decision needed is whether to salvage or not, depending on a range of ecological, forest management, and societal factors. The justification for Salvage Harvesting prior to 2024 included:

- Salvaging timber from fire-killed trees, for which the timber and societal values are otherwise lost if no action is taken, with sustainable yield losses offset (**Figure 84**), and (overleaf)

- The potential for post-fire natural regeneration to restore the site at no extra cost, while assisting to establish a lower density, and more structurally diverse, regrowth stand given the 'thinning effect' of salvage on naturally dense regeneration.

Forest damage is most commonly caused by bushfires, but also includes the less common windthrow events and damage caused by pests and diseases. In Victoria, Salvage Harvesting has occurred successfully following many bushfires since 1939 (**Section 5.1**), and more recently following windthrow. **Section 3.2** provides ecological details about the possible disturbances that can be experienced in Alpine Ash forests.

Figure 84. A majestic pole-stage forest of Alpine Ash in the West Kiewa Valley, killed by high intensity fire during Victoria's 2003 Alpine bushfires, being assessed by Forestry Victoria staff for Salvage Harvest.

Stands like this collectively held up to 600,000 m^3 of Ash timber, providing an opportunity to reduce the fire's impact on sustainable yield (Lawlor & Theobald 2005).

(Image: Amy Ware, 2003).

5.5 Detailed descriptions of silviculture systems

5.5.1 Clear-felling system, with or without seed trees

Description

The clear-felling silvicultural system, with or without seed trees, was practised successfully in Alpine Ash forests in Victoria since the mid-1950s (**Section 2.2**; Grose 1960b; Campbell *et al.* 1984). This system provided higher future wood quality and yield because of the control over seed supply and regrowth density by adjusting sowing rates (Fagg 2001), and the reduced overwood competition from fewer retained trees (Bassett & White 2001). However, it was more challenging to achieve social objectives because of initial impacts.

Clear-felling involved the removal of almost all commercial trees from a coupe, usually in one integrated operation; that is, all timber products are removed in the one operation (**Figure 85**). However, selected trees and small patches were retained for environmental purposes, mainly as habitat trees for fauna (see **Section 3.1** for fauna ecology). Regeneration was achieved by slash-burning (**Figure 81**) to create a receptive ash seedbed, followed by aerial sowing with collected seed. The system involved major disturbance of the site only once during a single rotation of approximately 80 years, unless a thinning of regrowth is undertaken, reducing rotation age to about 60 years (Fagg 2006; see **Section 5.5.3**).

Figure 85. Structural change of Alpine Ash forest through time under the clear-felling silvicultural system with slash-burning and aerial sowing of Alpine Ash seed. Pole stands naturally thin and the quality of habitat trees develops over time. See **Section 4.5** for details of stand development.

Operationally, clear-felling was the simplest silvicultural system for sustainable timber production (**Section 5**). This system allowed flexibility when opening the felling-face, reducing risk. It also reduced snigging distances and further improved the safety of workers. In short, clear-felling with slash-burning and aerial sowing was the most cost-effective means of harvesting Alpine Ash for timber and achieving regeneration (**see Section 4.5**).

Coupe planning

Harvesting operations and environmental protection requirements were guided by the Code of Practice for Timber Production (DEECA 2022). When planning a clear-felling coupe the following prescriptions overleaf may have been included:

- About 30% (by area) of tree cover was to be retained across gross coupe area (this may not been achieved for every coupe);
- For each Type 1 habitat tree, >4 additional habitat trees were retained (Type 2 or 3, as they existed) per hectare;
- Gaps between retained tree patches were not to exceed 150 metres;
- An additional retention in ratio of 1 ha harvest area to 0.05 ha of vegetation was retained. Placement needed to consider the best ecological and safety outcomes.
- The maximum slope generally permitted for harvesting operations was 30°.
- Soils were assessed prior to harvesting to delineate high erosion hazard areas.
- Maximum area of a coupe was 40 ha, but most coupes were 25 ha or less.

Implementing clear-fell operations (including regeneration)

Careful attention was paid to design and layout of roading, landings and snig tracks. Timing of harvest and site preparation with respect to season and wet weather aimed to minimise any adverse physical and biological effects of harvesting on soils.

Where the soil was wet and soft, generally after rainfall, cording and matting was placed on landings and snig tracks to distribute machine weight over a larger area and thus reduce soil compaction and rutting (Poynter 2004). This technique widened the operating window into shoulder and winter periods; a bonus for wet-forest species like Alpine Ash. Following harvesting, cording could be shifted or removed, and landings rehabilitated (see below).

Site preparation

After harvesting was completed, the coupe had to be regenerated. Preparation of a suitable seedbed was essential to this process. The main barriers to successful seedling establishment were heavy logging debris (slash), and/or grass and/or forest litter accumulation. Removal or re-distribution of this material by either fire or mechanical means was required (**Section 4.4** and as described below). It is now known that the best seedling establishment is observed on slash-burnt seedbeds, and increased seedling growth occurs on black (*c.f.* orange) ash-beds from high intensity fire (King *et al*. 1993b).

Broadcast slash-burning

Broadcast slash-burning (**Figures 81 & 84**) remains relevant today, and involved using high intensity fire, usually in autumn after the logging slash had cured. This consumed much of the slash and prepared an ash-bed. However, using the lowest intensity slash-burn consistent with adequate seedbed preparation, can reduce the physical effects on soil and nutrient losses from intense heat (Turner *et al.* 2011).

Some benefits of seedbed preparation by slash-burning are as follows:

- Generally less expensive per hectare than mechanical disturbance, especially for coupes more than 5 ha in area.
- By reducing the fuel levels on the coupe, burning minimises the possible damage to regrowth should the young coupe find itself in the path of a future bushfire.
- Biodiversity on clear-felled coupes can be enhanced by using fire. For example, *Acacia* is encouraged to germinate as heat breaks its seed dormancy (Harris 2004), leading to extra nitrogen in the soil (May 1999) and greater forage for Leadbeater's Possum.
- Growth rates of seedling eucalypts will be higher due to also to the 'ash-bed effect', increasing other available nutrients like phosphorous (Chambers & Attiwill 1994).
- Unlike machine seedbed work, burning can be safely used on steeper slopes (>20°).
- Heat from the fire will induce seedfall from any retained trees that bear mature capsules (Fagg 2001; Sebire & Fagg 2009; Bassett 2011).

Slash-burning is best carried out under ‘dry’ soil conditions to maximise the ash-bed effect. See Appendix 1 of Lutze & Geary (1998.) The burning may be carried out by a helicopter dropping incendiaries or by a manual system of people walking over the coupe using drip torches, starting from upslope positions with staggered starts downslope.

Mechanical soil disturbance

Mechanical site preparation also remains relevant today for forest restoration, and involved using a root-rake attached to a dozer or excavator head to disturb the surface soil and relocate slash into well-distributed rough heaps or windrows less than 6 m wide. The use of a root-rake, rather than a bulldozer blade, minimised soil movement and conserved soil and below-ground seed of understorey species (**Figure 86**).

Mechanical site preparation is best suited to flatter sites and those which contain little rock. While it can be conducted on slopes up to about 20° by bulldozer and about 25° by excavator, it should be avoided where possible on steeper sites for operator safety and soil protection. Excavators can also undertake spot cultivation, known as ‘lyrebirding’.

Figure 86. (Left) Root rake fitted to a bulldozer in Ash country, and **(Right)** an excavator lyrebirding targeted areas amongst grasses to establish seedlings. Grasses had been previously sprayed.

Care should be taken to conserve standing tree ferns and other significant understorey lifeforms that remain after harvesting. It is also important to minimise soil compaction and subsoil exposure, as these are barriers to seedling establishment (Rab & Kelly 2002). Generally, the disadvantages of using mechanical disturbance after clear-felling outweigh its advantages, when compared with slash-burning.

Further detailed information on site preparation is in NFSG No. 6 (Lutze & Geary 1998).

Seedling establishment

Following site preparation, regeneration was usually achieved by direct sowing of collected seed. The provenance of the seed used must be from the local area, or from an ecologically similar locality (Bassett *et al.* in prep.)[48].

[48] NFSG No. 2, *Seed Collection*, version 2, expected 2025 - previously (Wallace 1994)

Where scattered trees are left on the coupe, whether for seed or habitat, they could supply seed, especially if the slash is broadcast burnt given this induces seedfall.

For the science underpinning Alpine Ash seedling establishment, see **Section 4.4**.

Seed collection

Seed collection can be undertaken using traditional on-coupe ground collection, by collecting mature, seed-bearing capsules from the crowns of recently felled trees. More commonly seed is collected by an off-coupe climbing operation that removes up to 50% of the canopy from standing, live trees to provide a source of capsules (**Figure 87**). Climbing trees for seed provides high flexibility, and seed is collected from a range of possible sites, including State forest areas not available for timber harvesting, provided the operation complies with State government authorisation protocols (Bassett et al. *in prep.* 2025 after Wallace 1994).

Figure 87. Dan Jenkins (Eddcon Pty Ltd) climbing an Alpine Ash tree to collect seed in the Dargo area, Alpine National Park.

The seed is extracted from capsules dried in a kiln (Wallace & Fagg 1994), tested for viability and vitality, and then kept in dry, cool storage (<5°C) in readiness for aerial or hand sowing. Note that storage of early first-year seed is not recommended for Alpine Ash (see **Section 4.1.3**). Low humidity storage of Alpine Ash seed is required to avoid strengthening its primary dormancy (DSE 2018).

Sowing seed

The recommended standard sowing rate for Alpine Ash is 125,000 viable seeds per hectare (Fagg 2001). However, provided seedbed receptivity and seed vitality meets certain high standards, this sowing rate may be <u>reduced</u> according to **Table 11**.

Table 11. Sow rate reduction guidelines for Alpine Ash, relative to the quantity of receptive seedbed.

% of 16 m^2 plots which have >50% receptive seedbed	% of full sowing rate
<75%	re-prepare all/part of site
75–79%	100% (no reduction)
80–90%	80%
>90%	60%

Sowing techniques are described in detail in Fagg (2001). Helicopters have been regularly used for sowing coupes since the early 1990s. A specially designed seed-metering device is fitted into the helicopter along with a seed hopper (**Figure 88**). The Ash seed is spread in 20m wide swaths as the pilot uses a GPS guidance system to fly systematically across the coupe; the operation is termed heli-seeding.

Ground-based seeding, using a tool such as the Maryuma seed 'spinner', may be an option for irregular or small areas, but would be more expensive per hectare than heli-seeding.

The sowing rate is converted to an application rate (kg/ha) based on viability (vs/kg):

$$AR\ (kg/ha) = \frac{\mathrm{SR\ (vs/ha)}}{\mathrm{V\ (vs/kg)}}$$	Where: AR = Application Rate SR = Sow Rate for the species V = Seed-lot viability
Example: If SR = 125,000 vs/ha, and V = 95,000 vs/kg, then AR = 1.3 kg/ha	

Time of sowing

Alpine Ash seed must undergo dormancy-breaking stratification under snow for at least 4 weeks before it will adequately germinate in the field (Grose 1963). Note, recent laboratory tests and field experience indicates that 6 weeks is better (Bassett 2011). **Thus, sowing time in an average season should be no later than 30 June**, but mid-July is possible, although this runs the risk of insufficient stratification time to break seed dormancy in all but the coldest of winters. See **Section 4.3** for details of Alpine Ash seed biology.

Figure 88. Paul Kneale (formerly VicForests) loading Alpine Ash seed into the helicopter registered VH-NYX ready for sowing following the 2020 bushfires.

Planting

Planting is an option where seed is in shortage, or where advanced seedlings are needed for more rapid establishment. However, planting is more expensive compared to sowing seed.

Note that under average conditions, one kilogram of seed produces about 3,000 seedlings if directly sown to the seedbed on the coupe, but the same kilogram used to raise seedlings in a nursery should result in about 30,000 seedlings. Seedlings for planting are raised in root trainer tubes, nutrient loaded, and then planted by hand as soon as possible after site preparation is completed (Bassett *et al.* 2014). Note that seedlings must be hardened-off before planting at all Alpine Ash sites, to survive frosts and snow.

Planting needs to be considered where there are concerns about competition from other vegetation, especially (Tussock) Snow Grass *(Poa* spp.) in some typical Alpine Ash areas (**see Boxes 14 & 16, Chapter 7**). This may need to happen, for example, when slash-burning has not been very effective, although competition would first need to be reduced.

Planted seedlings are often preferentially browsed, so some type of guarding, fencing or use of browsing repellent may be required, as described below, and this adds to the cost.

Seedling protection

Where browsing by deer, wallabies, or rabbits is likely to be a significant problem, the protection of seedlings using tree guards or fencing should be considered. Although expensive, tree guards may prove more cost-effective than the fencing option on small or highly fragmented areas. Cattle may be present in some alpine areas, but little browsing occurred with some trampling during reforestation on Connor Plains (Bassett *et al.* 2012).

Fencing is generally more cost-effective ($ per ha) on larger coupes. Although it is also expensive, 'internal deer fencing' is effective and can be re-used after the trees have grown out of reach of the wallabies and deer, after 2–4 years. Deer fencing is strong wire mesh 1.8m high, held in place by long steel pickets. Cost, as at 2022, is very high at approx. $2,000 per 100 metres. Regular maintenance of fences to remove trees that have fallen on them and plug up holes made by wombats, is required.

See Section 4.4.1 and NFSG #7 Browsing Management (Poynter & Fagg 2005) for detail related to Alpine Ash and other control measures and browsing risk assessments.

Seedling monitoring

Following The Code (DEECA 2022), the results of seedling establishment operations must be assessed within 3 years of sowing and/or planting. See NFSG No. 10, version 2, *Eucalypt Stocking Surveys and Regeneration Monitoring* (Bassett *et al.* 2014) for detailed procedures and standards when undertaking a stocking survey. If the standards are not met after 3 years, then the site must be re-treated until it is adequately regenerated. Retreatment techniques for forest restoration are described in **Chapter 7**.

5.5.2 Variable Retention systems

Description

The Variable Retention Harvesting (VRH) was used as an alternative to clear-felling, and was appropriate to situations where there were important fauna values or landscape constraints. Regrowth Retention Harvesting (RRH) was a form of VRH where >50% of the harvest area was within 1 tree height of retained forest. Variable Retention systems could retain trees in patches for extended periods up to their natural life span (**Figure 89**). The density and spatial distribution of retained trees, and the length of time for which they were retained, could be varied to meet specific flora, fauna or aesthetic objectives.

This system produced a multi-aged forest in any single coupe (CFTT 1997b), and simulates the effect of moderate intensity bushfire in which a proportion of trees survive. It was primarily suited to stands where there were several hollow-bearing trees per hectare to be retained to provide for habitat or other values. Limits on gap size, recruiting additional retained vegetation, and ensuring ecological outcomes were key objectives. Variable Retention could also incorporate dispersed retention to complement retained patches. *Note - A system variation (VR 2) is one where harvest intensity was less, meaning there was more habitat retained, and regeneration burns were low intensity or the coupe mechanically prepared* (VicForests 2019).

Figure 89. Structural change of Alpine Ash forest through time under the Variable Retention silvicultural system with cooler slash-burning and aerial sowing of Alpine Ash seed. Note the additional retained elements not present on clear-fell coupes (**compare Figures 80 & 81**). See also **Section 3.1.4**.

One negative effect of retained patch edges and individual trees is that they impose a suppressive effect on regeneration established on the harvested area and this edge effect becomes more significant as the coupe size is reduced (Bassett & White 2001). For this reason stand development may take longer – nominally 100 years.

The Variable Retention system more fully met habitat requirements, such as structural diversity for arboreal mammals and other hollow-dependent fauna that were not well catered for by clear-felling (Lindenmayer & Franklin 2002; Lindenmayer 2007). Trials began in the Central Highlands in 2003 where 1.5 ha and 0.5 ha 'islands' within Ash coupes were retained on the basis that 'islands' of forest will more likely survive slash-burning and strong winds than dispersed retained trees (Flint & Fagg 2007).

Coupe planning

For Variable Retention coupes the planning prescriptions usually also included:

- Where 3-6 Type 1 habitat trees per ha are present, retain an additional 6-12 Type 2 and Type 3 habitat trees per ha across the active harvested area;
- Ensure gaps between retained aggregated retentions don't exceed 150 metres; and
- Use slash-burning where prudent, with a preference for less intense burns to minimise damage to retained trees.

Implementing Variable Retention

Harvesting

Where retained patches, 'islands', or isolated trees were retained, care was taken to avoid physical damage to them during harvesting of the surrounding forest.

Site preparation

Careful slash-burning was feasible, although it may have been difficult to avoid some damage to retained patches. The impact of burning on retained habitat trees or patches was greatly reduced by creating extended mineral earth breaks around them, at least 3m from the base of any tree, avoiding heavy accumulation of slash adjacent to retained areas, particularly downslope. Ignition was staged to slowly bring the fire past retained areas. Ignition in Variable Retention coupes was generally by hand rather than via helicopter, as hand lighting gave more control over the lighting pattern.

If damage to retained trees from burning for seedbed preparation was found to be a major risk, rough heaping of harvesting slash was an alternative considered if the slope allowed (**Figure 90**). Rough heaping, however, has some negative environmental effects, such as exposing bare soil to erosion, and damaging plant species such as tree ferns and those that regenerate from tubers and root stocks.

Seedling establishment

Aerial sowing of Variable Retention coupes was undertaken as if they were clear-felled coupes (see **Section 6.1.3**); that is, sown area is the gross felled area of the coupe. Some natural or fire-induced seedfall from retained tree patches or individual trees could be expected, depending on their seed crops, but this was not relied upon. If good seed crops were predicted, a lower rate ‘supplementary’ sowing was an option.

Seedling protection

As for the clear-felling and seed tree system (see **Section 5.5.1**)

Seedling monitoring

As for the clear-felling and seed tree system (see **Section 5.5.1**)

Figure 90. Airborne. An Ash species coupe in the Hume Region harvested by VicForests in about 2011 using the Variable Retention system, with two retained aggregated Islands and some dispersed retained individuals. To ensure the protection of islands from fire, and also the neighbouring coupe’s already-established regeneration, fire has been avoided and the site mechanically disturbed with well-spaced windrows prior to sowing.

5.5.3 Thinning system

Description

Thinning is defined as the felling of part of a forest stand or crop with the aim of increasing growth rate or health of the retained trees (**Figure 91**) (DEECA 2022).

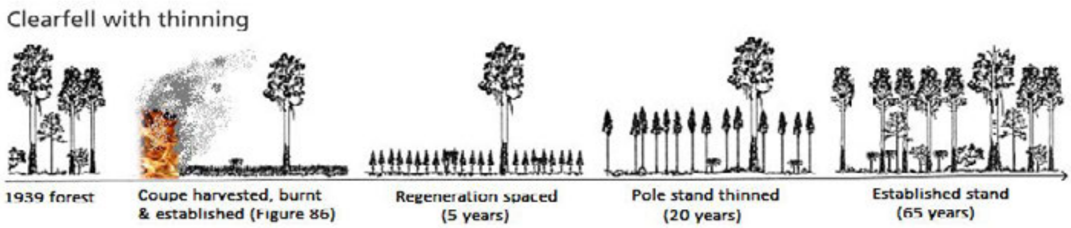

Figure 91. Structural change of Alpine Ash forest through time under the Thinning silvicultural system for even-aged regrowth. Early spacing and pole-stage thinning encourages faster growth and shorter rotation age. See **Chapter 6** and **Section 7.2.3** for use of Thinning for 'active management'.

The main objective of commercial thinning of even-aged regrowth was to improve the potential of the retained trees for yielding high quality veneer logs and saw logs, whilst using the felled trees for wood products and producing a financial return early in the life of the stand (Kerruish & Rawlins 1991). Given that most trees removed in a normal 'from-below' thinning operation will be those which would have died over time, through natural competition, this yield of timber early in the rotation is a major economic benefit to the forest manager. Thinning of regrowth eucalypt forest, resulting from fire or regeneration after timber harvesting, is likely to also result in benefits to water production, fuel reduction, and wildlife habitat (Ryan 2013; Volkova *et al.* 2017).

Another significant benefit from thinning, is the potential for increasing resilience to fire, derived from faster growth, increased bark thickness, and a break-up of crown continuity (Keenan *et al.* 2021).

The dominant and sub-dominant trees remaining after a thinning respond well in diameter increment and their gross basal area production per hectare is very close to that of unthinned even-aged stands provided the thinning intensity is not more than 40-50% by basal area (Webb 1966). For Mountain Ash, a species similar to Alpine Ash, the growth model STANDSIM indicates that a regime with thinning at 25 years (143 m^3/ha of mainly pulpwood) and clear-felling at 65 years (770 m^3/ha of mainly sawlogs) compares with a total yield of 930 m^3/ha at 80 years if unthinned (Rawlins 1991).

Planning for thinning

Planning for commercial or other thinning is a complex task that combines:

- the aim of the thinning program, in terms of the product or outcome desired
- the area and suitability of the even-aged stands
- the identification of constraints, such as approval processes, seasonal conditions, roading and company scheduling, and
- data collection before, during and after the thinning operation.

A pre-thinning assessment of each stand proposed for thinning should be carried out, and decisions made according to the recommendation for each of the 9 criteria in **Table 12**. The aim should be to reduce the basal area by about 50%.

Implementing thinning operations

Commercial thinning in Ash regrowth was best carried out using the ‘outrow and bay’ method (**Table 13**; see also Fagg 2006). The ‘rows’ (or tracks) made by the feller-buncher machine were approximately at right angles to the contour to assist the stability of the machinery. The ‘bays’ were strips between outrows.

All trees in outrows were felled and removed, while only the smaller trees in the bays were felled by the feller-buncher by reaching into the bay from outrows on each side. A forwarder machine subsequently picked up bunches of logs, usually in 6 m lengths, that are left just inside the bays, and transported them off the coupe for loading onto waiting trucks.

Thinning significantly opens up the canopy, allowing a higher light penetration and ‘room’ for growth and branch development (**Figure 92**).

Table 12 Suitability of Alpine Ash stands for commercial thinning (Fagg 2006).

Criterion		Recommendation	Reason(s)
1.	**Age**	22–45 years	*Lower limit* – to maximise the period of growth response *Upper limit* – stands/trees beyond this age are generally too large to thin without causing excessive damage
2.	**Slope**	Generally <18 degrees	For ease and safety of machine operation, and to help minimise tree damage
3.	**Basal area**	Average not less than 35 m^2/ha	To allow for an economic yield
4.	**Tree volume**	Most trees to be removed to be at least 0.2 m^3	To improve the economics of the thinning operation
5.	**Height** **Site quality**	Mean dominant height >28 m	To ensure the stand will derive a good growth benefit from the thinning
6.	**Height to first green branch**	Average not less than 12 m on co-dominant trees	To ensure a good, clear log length in retained trees
7.	**Access**	Exposed rock, old logging debris, and understorey not excessive	To ensure than machinery can work efficiently and safely
8.	**Area**	Minimum stand area of 10 ha	To minimise floating of machinery
9.	**Overwood basal area**	Average of <4 m2/ha	To ensure max response from thinning, and to minimise OH & S issues

Figure 92. (Left) An open but 'crowded' crown structure in an unthinned Alpine Ash forest. **(Right)** Crowns are spaced following thinning, enabling growth and crown development. Note that some epicormic growth has developed due to increased light (right image: P. Fagg)

Table 13. Outrow and bay widths for two slope classes for thinning of Alpine Ash regrowth.

Slope	Outrow width (max)	Bay width (max)
<15 degrees	4.5 m	14 m
>15 degrees	4.5 m	12 m

Damage to retained trees

The wood of trees will be almost certainly degraded following bark removal or breakage of the bark-wood bond, even if the bark is not removed. Damage is defined as follows:

- Breakage of the bark-wood bond anywhere on the main bole (bark may not be removed);
- Severe impact on bole (bark-wood bond breakage not clear) as indicated by bad bruising or rubbing; and
- Breakage of 30% or more of the crown

NFSG No. 13 (Fagg 2006) requires that damage be restricted to no more than an average of 15% of retained 'crop' trees assessed over a sampled 6 hectare area.

In the Young Eucalypt Program, White & Kile (1991) studied defect development following stem wounding in thinned 23 and 75 year-old Mountain Ash stands. Discolouration and decay extended rapidly through the sapwood to the heartwood and formed extensive columns above and below the wounds. Such stain and decay leads to the down-grading of sawlog quality. It is predicted that Alpine Ash would respond in a similar way to Mountain Ash, but research on this matter is needed.

Epicormic shoots may develop in the eucalypt crowns and on boles if the stand is thinned too heavily too quickly (see **Figure 92**), but epicormics are mostly confined to intermediate/suppressed trees, rather than the dominant retained trees, and is often related also to insect damage. If no more than 50% of the stand basal area is removed, epicormic development will be minimised. Note that thinned areas may also be subject to windthrow and unseasonal snow damage if thinning is too heavy.

Factors likely to influence incidence of tree damage are:

- *Type of machinery.* Fixed head feller-bunchers have the capability to reduce potential damage because they have more control over the placement of the tree.
- *Slope.* Damage incidence and slope are positively correlated. While areas thinned should have a slope generally less than 18°, turning of machines even at slopes of 12° is difficult. Slippage by machines on wet soil or slash may also result in damage.
- *Landings.* Trees around landings are invariably damaged due to log stacks and increased machinery movement.
- *Design of extraction routes.* The design of outrows and extraction routes (layout and density) affect how retained trees can be damaged by forwarding operations. For example, if tracks are not at right angles to the contour, machinery can strike trees.
- *Supervision.* Close supervision, especially of inexperienced operators, can reduce the level of damage, through timely feedback on damage incidence or retention density.
- *Obstacles.* The frequency and distribution of obstacles on the ground such as rocks, holes, and old stumps and debris from previous harvesting operations can cause unpredictable machine movements. Dense understorey may constrain visibility and movement which can also lead to inadvertent damage.

Refer to NFSG No. 13 *Thinning of Ash Regrowth (*Fagg 2006) for assistance with coupe planning, field marking, thinning specifications, felling and utilisation, and monitoring procedures.

Flora and fauna – impacts from thinning

Thinning using mechanised equipment results in immediate structural change in the vegetation; such as, tree density is less and part of the understorey, especially that on and near outrows, is initially flattened.

There has been little research of the impacts of thinning on flora and fauna in Alpine Ash forests. However, a number of studies (summarised by Kutt *et al.* 1995) of thinning in the mixed species forests, dominated by Silvertop Ash (*Eucalyptus sieberi)* in East Gippsland give some guidance on expected initial impacts:

- Despite a dramatic alteration of vegetation structure, there was no evidence that any plant species was eliminated by a single thinning operation.
- Thinned forest contained the highest density of basking skinks, due to increased sunlight reaching suitable basking substrates.

- Total diurnal bird density was highest in old forest and lowest in thinned regrowth, although the number of species in each was similar. Nocturnal birds preferred thinned stands, compared with unthinned stands and old forest.
- Thinning did not seem to disadvantage possums, but retention of any old trees was important if possum populations were to be maintained. Bat activity was not significantly affected by thinning.

In summary, commercial thinning in mixed species regrowth, found through research mainly within Silvertop Ash dominated forests, has little significant negative impact on flora and fauna. However, as Alpine Ash is very different from mixed species eucalypts, new research is needed and special precautions may be required - a point still relevant as 'active forest management' practices further develop. For example, Silver Wattle and understorey connectivity could be impacted, reducing suitability for Leadbeater's Possum if present.

Thinning in water catchments

Since the 1950s hydrology research has been conducted by the Melbourne & Metropolitan Board of Works in its water catchments (**Figure 93**), which are largely forested with 1939-aged Mountain Ash and Alpine Ash. One of these studies (O'Shaughnessy & Jayasuriya 1993) showed that a uniform thinning which reduced the basal area of a 37 year-old stand by about 50%, increased streamflow by about 25% or 100 mm/yr over the following 10 years, after which the increase reduced. However, damage to retained trees was high (33%).

Figure 93. Alpine Ash is an important forest-type in Melbourne's water catchments, like here in the Upper Yarra (Image: Nick Garden, Melbourne Water). See also **Figure 26**.

Strip thinning experiments were subsequently set up (in which damage levels were minimal) in the Crotty Creek and the North Maroondah catchments. The strip thinning in 1979-85 reduced the total basal area of the 1939 stand by 50% by felling 35 m wide strips (which were left unregenerated) and leaving alternate 35 m wide retained strips. These strips remain observable from the air today. Streamflow increased by 26% over 5–10 years, mostly as base flow in the period October-January each year. Although 50% of the basal area (equates to volume) was removed, gross volume increment after thinning was reduced by only about 33%. The increase in the streamflow reduced to 'normal' after about 15 years (CNR 1993).

Analyses showed that strip thinning has the potential to increase the combined wood and water economic output from such catchments, and that water quality would not decline provided that normal protection measures, such as retained buffer strips and barriers on snig tracks, were implemented (CNR 1993).

Today, thinning objectives in water catchments are restricted to increasing water production and reducing fire risk, and could form part of a silvicultural strategy of actively managing Victoria's native forests (**Chapter 6**).

5.5.4 Salvage harvesting system

Description

Section 5.4 provides an introduction to salvage harvesting timber from damaged forests (**Figure 94**), and **Section 5.6** provides the Decision Support System (DSS) for such operations.

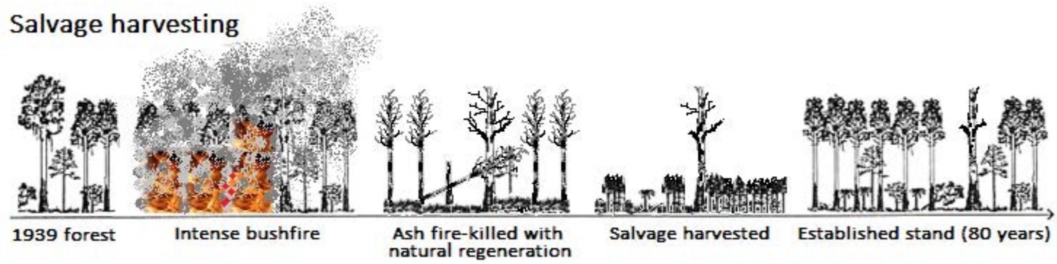

Figure 94. Sequence of events and structural change of Alpine Ash forest through time under the salvage harvesting silvicultural system. Regeneration can occur naturally from seed induced to fall by the bushfire. Harvesting without delay minimises damage to regrowth while it is small. The stand develops over time similar to those after clear-felling (See **Section 4.5** & **Section 5.5.1** for details).

Salvage harvesting has in the past been defined in Victoria as, "*Timber harvesting operations to recover timber following wildfire, storms, floods, disease, insect attack or other events that cause significant tree mortality or damage"* (DEPI 2014a as amended 2022). After the native timber industry closure in Victoria during 2024, and the shift away from commercial timber production, some elements of the salvage harvesting systems remain relevant for future active forest management; for example, recovery of fibre such as firewood or speciality timbers, management of fuel loads to increase forest resilience to fire, or as an element of forest restoration (see **Chapter 7**).

The most common type of salvage harvesting undertaken in the past was following severe bushfire that killed the majority of trees in an area. As described in **Section 3.2.1**, Alpine Ash is usually killed outright during a bushfire of moderate intensity or greater; not having the capacity to recover by epicormic shoots, as do most other eucalypt species. Over the past two decades, salvage harvesting has most prominently occurred following the 2003, 2006/07 and 2009 bushfires, with earlier historic examples (**Section 5.1**). The principal recorded example of salvaging timber following bushfire is Theobald & Lawlor (2005).

Occasionally there are strong windstorms or localized tornados that blow down areas of Alpine Ash forest (see **Section 3.2.2**). In this situation, most of the leaves and branches will be green and intact, and the tangle of horizontal tree trunks would make any timber salvaging a difficult task. However, if such ‘wind-thrown’ areas were large enough, say >10 ha, salvage could be an option if the logs were utilisable and the area had good road access. In future, some form of salvage operation in storm affected areas might also be undertaken to manage fuel loads, to extract fibre such as firewood, to manage hazardous trees, or applied as part of a forest restoration program (**Chapter 7**). Storm damaged areas also provide opportunities for seed collection, if seed crops are present in the area and access is possible prior to capsules opening and seed shedding.

Section 3.2.3 describes some insect and fungi species which may damage Alpine Ash. Generally, however, damaged trees recover from such attacks, and intervention to salvage harvest such trees has never been warranted.

Planning for salvage harvesting

While the commercial timber industry operated in Victoria, the harvesting of timber from burnt forest was controlled by prescriptions that managed issues such as choice of harvesting location, coupes size and aggregation, habitat protection, water quality, protecting trees and plants that had naturally started to regenerate post-fire, controlling weeds and diseases, forest management values, and ensuring prescribed exclusion areas to protect habitat and the maintenance of forest type (DSE 2008). **Section 5.6.2** provides a DSS to assist decision making during the planning phase.

Post fire damage and timber assessments

Following a major bushfire in Ash forests, damage assessments at the landscape scale are undertaken to determine forest recovery needs (**Chapter 7**, but specifically **Section 7.4**). For salvage harvesting, additional assessments were concurrently undertaken by VicForests at the finer scale to identify suitable stands for salvage harvesting on the basis of fire intensity, age class, access, and the potential volume of merchantable timber that could be salvaged.

Areas designated as Fire Severity Class 1, 2 or 3 were considered for harvesting, with ‘green patches’, such as areas classed as having 15-40% Fire Severity Class 4 or 5, protected from harvesting until the regrowth around the patches had sufficiently matured and developed the capacity to naturally regenerate should another bushfire occur (**Figure 95**). Even Class 3 damage usually includes live, surviving Ash that may require exclusion from harvesting (see Chapter 8 of DEPI 2014b; DSE 2008; VF 2023).

Regarding Fire Severity Classes (see also **Table 17**, **Section 7.4.3**):

Class 1: 90–100% of eucalypt crowns burnt, no leaves remain (**Figure 95**).

Class 2: 60–90 % of eucalypt crowns are scorched and some crowns are burnt. Scorched, dead, red-brown leaves usually remain on eucalypts (**Figure 95**)

Class 3: 30–65% of eucalypt crowns are scorched, with live trees prominent.

Ash stands of 1939 fire origin were 84 years old in 2023 and certainly contained merchantable log sizes, as would most stands of 65 years of age. Stands 50 – 65 years old would have had fewer sawlog size trees and more pulpwood size trees per hectare; the pulpwood-to-sawlog ratio increasing with decreasing age. By about 18-24 months after a bushfire, the wood in the standing killed trees develop cracks, known as ‘checking’, due to the drying out of once-sap-filled wood, thus reducing the sawn timber quality. This means that it was highly desirable that salvage harvesting be undertaken within two years of the fire. Salvage operation prescriptions apply “*within fire-affected forest until the beginning of the third winter following the wildfire*” - Chapter 8 of DEPI (2014). Specific prescriptions are detailed in DSE (2008).

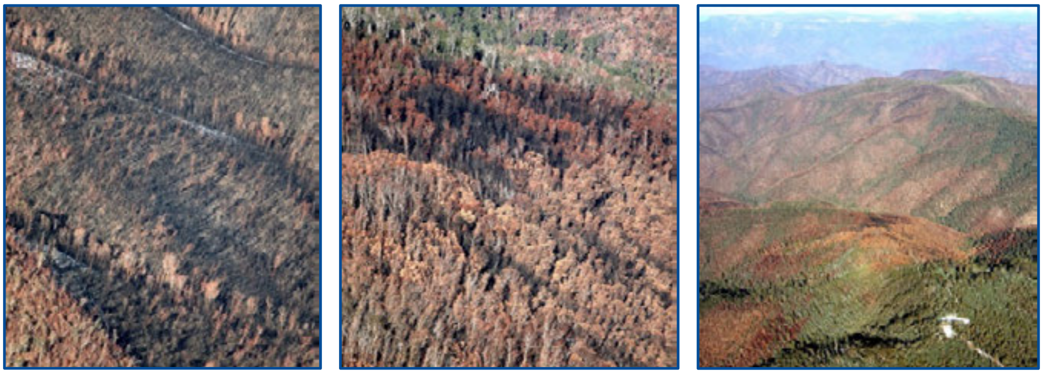

Figure 95. Airborne. Fire Severity Class 1 **(left)**, Class 2 **(centre)** in Alpine Ash, and a landscape with burnt and green patches **(far right)**. The green patches would not have been available for immediate harvesting. These images were captured by Forest Solutions during rapid response damage assessments following the 2019 Macalister Complex bushfires **(Chapter 7)**.

Seed crop assessments and seedfall estimates

Well before any salvage harvesting began on a potential coupe, the extent and amount of seedfall per hectare from the standing dead trees was first estimated (see below in ‘**Regeneration**’). Post-fire techniques for assessing what seed crops would have been present at the time of the fire are similar to post-fire strategic seed crop assessments, and operating procedures are available (DELWP 2020; VF 2009).

See ‘**Flora and fauna’** this section (**page 126**) for evaluating seed crops in young regrowth to determine when green patches could be harvested in a burnt landscape.

Coupe planning

In the coupe planning process, factors common to all harvesting, such as slope restrictions and the need for buffer strips along watercourses to protect water quality, need to be taken into account. Buffer strip widths have to be increased above usual due to exposure of soil by the fire. The State’s Management Standards and Procedures for Timber Harvesting (DEPI 2014b) specify where landings and boundary tracks should be placed. Table drains and culverts must be well maintained to allow for increased water flows along roads after rainfall in a burnt environment.

The maximum coupe size allowed for salvage harvesting in State forests was 120 ha, and no size restrictions applied to aggregates of fire salvage coupes (DEPI 2014b). See **Section 6.4.4** for habitat retention requirements.

Timing of harvest

For forest fires that kill Alpine Ash in summer, it is highly desirable that salvage harvesting be scheduled as soon as practicable (**Figure 96**), to allow a maximum amount of harvest before winter begins, during which snowfall would make harvesting problematic, if not logistically, impossible.

A second reason to begin salvaging timber well before the first winter is to minimise the area of soil impacted by machine disturbance where young Alpine Ash seedlings may begin germinating in the following September-November period and onwards, following the over winter stratification of fallen seed.

Figure 96. Mechanised harvesting is the safest and most efficient form of salvage harvesting in native forests. Here an excavator with boom-mounted falling head is processing fire-killed Alpine Ash in NE Victoria during January 2004, following the 2003 bushfires.

(Image: Caitlin Cruikshank).

While some trees could be harvested for pulpwood after the approximate two year period, Harvesting when young regeneration is present can be acceptable, given the flexible nature of young stems. In contrast, regeneration over two years of age can become brittle and snap as heartwood develops stability with increasing height. Mechanised harvesters (**Figure 96**) have enhanced this regrowth protection during harvesting (Theobald & Lawlor 2005).

While some trees could be harvested for pulpwood after the approximate two year period, for which use checking is not a great problem, safety becomes a consideration, given branches of a tree that are dead and drying are more likely to break off during the felling process, putting machinery and their operators at risk.

Implementing salvage harvesting

Silvicultural system

Clear-felling was the usual harvesting system employed in most salvage operations (see **Sections 5.3.1 & 5.5.1**), unless green patches had been prescribed for retention, and these would be left unharvested (see **Flora and fauna conservation** below; DEPI 2014b). Other live trees outside prescription, preferably in groups and that were not fully scorched in the fire to survive long term, could also be retained.

Regeneration

Alpine Ash is totally dependent upon seed for its regeneration (**Chapter 3 & 4**), and evaluating the extent of fire-induced seedfall from the standing dead trees, before any trees are felled for salvage, was estimated using techniques described in **Section 7.4.5**, but also in detail in DELWP (2020) and VF (2009). If good seedfall was predicted, including an adequate quantity and evenness of spread, then no additional artificial sowing was required (**Figure 97**). Given salvage harvesting occurred in a timber production context, full stocking was required. To achieve this, and because of expected seed losses due to various agents (see **Section 4.1.4**), an estimated canopy seed crop of 300,000 vs/ha was required to achieve an effective seed fall of at least 125,000 vs/ha (Bassett 2011; Lutze & Bassett 2020).

Figure 97. Carolyn Slijkerman and Emily Steer assess Alpine Ash cotyledon density and ground capsule-fall **(at right)** in the Marysville district following the 2009 bushfire. Such assessments are crucial for estimating the expected seedfall induced by the bushfire. (Images: Caitlin Cruikshank).

If predicted seedfall is not adequate, supplementary aerial sowing of seed of a suitable provenance in the winter months immediately after the fire, even while salvage harvesting is underway, was required (see **Section 5.5.1**). In years when seed was in short supply, environmental stocking could be considered, requiring a smaller in-canopy seed crop of 150,000 vs/ha (Bassett 2011; Bassett *et al.* 2014b; Lutze & Bassett 2020).

If harvesting is occurring in Fire Severity Class 1 & 2 burnt areas, the fire will have killed most vegetation on the site and left a suitable ash seedbed within which eucalypt seed can germinate. While salvaging will produce a lot of slash consisting of scorched, dead branches and upper tree boles, this material can be left where it lies, and the harvested coupe should need no specific site preparation at least within 18 months after the fire.

However, in the case of wind storms, no such 'cleansing' fire has occurred, leaving no receptive seedbed. Tracked machine operations to salvage timber can create some disturbed-soil seed beds, but it is likely that a specific site preparation will be required to encourage forest recovery, consisting either of slash-burning or further machine disturbance (see NFSG No. 6 *Site Preparation* - Lutze & Geary 1998).

Cording and matting can be used to protect soil values and extend operating conditions into wet seasons.

Flora and fauna conservation during salvage harvesting

Dead or dying trees that have some value for future habitat, for example those with hollows that may be suitable for certain arboreal animals, require retention, and there should be no more than 200m distance between areas of these retained habitat trees.

Victoria's Management Standards and Procedures also required machinery to be excluded from a minimum of 15% of the gross coupe area to facilitate the recovery of understorey species, with a minimum 20 metres width of such excluded areas (Section 8.1.4.2 of DEPI 2014b). In particular where tree ferns are present, plans can be made to include these in the exclusion areas.

Ash Green Patch Retention (GPR)

During the development of salvage harvesting prescriptions following the 2006/07 bushfires, strategies were being developed to minimise the impacts from harvesting operations on the recovery of biodiversity following the bushfire that killed Alpine Ash forest. This included the retention of any surviving forest patches, including those unburnt or only partially burnt. During the 2008/09 period, these prescription were refined into an Ash Green Patch Retention (GPR) prescription, supported by the relevant Codes of practice and their reviews since 2014 (DEPI 2014a). Under these prescriptions, no green patch could be harvested until the surrounding regrowth forest that regenerated after the bushfire was assessed as reproductively mature, and so could be regarded as possessing the capacity to naturally regenerate should another bushfire occur.

At its closure in January 2024, VicForests was developing a technique for determining the natural regeneration capacity of post-fire Ash regrowth in the vicinity of green patches in State forest General Management Zone, to help determine when the green patches could be harvested without compromising the ongoing natural replacement of local populations and recovery of biodiversity. The technique is based on a ground assessment of seed crops, at an appropriate sampling intensity across the landscape, the timing of which could occur at about the expected timing of reproductive maturation; being about 15-20 years of age (see **Section 4.1.2**; VF 2023).

5.6 Decision Support Systems for harvesting Ash timber

The application of silvicultural systems for sustainable wood production involved engaging appropriate management systems in a natural environment where not all of the important variables were under the forest manager's control. Choice of silvicultural system was made to ensure the greatest probability of success, with contingency plans when exceptional or non-average conditions occurred. These management systems had a number of key elements, including Operating Procedures that applied guidelines and prescriptions, which were learnt and adapted over time with inputs from experimental science and operational trials. Specialists trained and competent in the science underpinning silviculture, and the management systems themselves, were critical to success.

The characteristics of the natural forest environment include the ecological processes present and their responses to disturbance and, most importantly, variability. In Alpine Ash, seasonal variability in weather conditions had to be addressed by adaptive management systems. The key variations in Alpine Ash forests are the number and severity of frosts, the depth and duration of snowfalls and impacts of summer droughts (**Section 3.1.1**). Unfortunately, these factors are challenging to predict.

A key systems element designed for timber production was a tool to assist the forest manager during the decision-making processes and to form a basis for continuous review and improvement of practices. This tool is known as a Decision Support System (DSS), prompting consideration of a number of key variables known to impact on the successful harvest of timber, minimisation of environmental impacts, and regeneration performance.

In Victoria, there are currently two DSSs for Alpine Ash: one for choosing the correct silviculture system to use, from a range of alternatives, during routine timber harvesting of live healthy forest; and the other is to assist the decision of whether to Salvage Harvest, or not, following a major disturbance that has killed or severely damaged an Alpine Ash forest.

5.6.1 DSS for routine timber production in Ash forests

A DSS was available for applying routine silviculture in Alpine Ash forests for timber production, and VicForests had a leading role in its development and application (VicForests 2016). The DSS provides a framework for assessing and recording essential silvicultural factors and decisions on an individual coupe (**Figure 98**). It is a flow of decision points (DPs) that are dependent on the preceding decision usually requiring a simple ‘yes’ or ‘no’ to proceed.

This DSS was an operational tool, designed for use by field officers responsible for planning and supervising commercial timber harvesting and regeneration operations. The DSS ensures that relevant pre- and post-harvest issues have been identified and decisions made to maximise regeneration success and maintain biodiversity.

First decision point – DP1

The first decision point focuses on the current stand structure of Alpine Ash, to identify if a final harvest of mature stems was able, or if a thinning of regrowth was required.

For final harvesting of mature forest

The final harvest path (*via* DP2-DP6) then decided if clear-felling was suitable, or if a viable alternative was required. Choice of silvicultural system was based on fauna habitat values, the potential of the habitat to be enhanced by the retention of regrowth trees for future habitat by applying Variable Retention silviculture, and whether the system alternative to clear-felling was suitable for the site conditions regarding safety and expected regeneration performance. There was scope to consider additional societal considerations, either at the local community level or based on broader cultural concerns.

The last decision required was about site preparation (DP8), given the techniques must be designed to protect and maintain the retained elements for the purpose of their retention.

For thinning regrowth forest

The thinning path (*via* DP7) remains an option today, and checks the suitability of the site for such operations, considering variables such as slope, basal area, and parameters about forest structure. It is important to note that thinning to achieve any forest management objective can generally be unsuitable for certain sites and forest structures.

5.6.2 DSS for Salvage Harvesting in Ash forests

A DSS was also available to assist with decisions related to Salvage Harvesting, and for choosing the appropriate options available for potential sites (VicForests 2008). Salvage Harvesting was only ever applied to damaged forest, where the available timber otherwise became an opportunity cost regarding its utilisation should harvesting not proceed.

The Salvage Harvesting DSS (**Figure 99**) helped navigate key prescriptions developed by the State government to enable Ash timber to be harvested before it degraded, to ensure key habitat elements were maintained to assist biodiversity recovery, to minimise risk to water quality, to protect the regeneration of Ash seedlings and other native flora, impair the proliferation of weeds, and which provided a safe work-space for industry personnel.

The first decision point relates to fire damage severity, with the simplest decision to salvage focused on Severity Class 1 or 2 (**Table 17**, **Section 7.4.3**), being largely fire-killed. Forests with surviving patches of Ash and varying levels of fire-killed Ash are classified as Severity Class 3. Identifying areas with low levels of fire-killed Ash (<50% coupe area) is important, because ‘green patches’ of certain size and shape needed to be retained as a biodiversity refuge for a prescribed period (DSE 2008). The remaining decisions were related to natural Ash regeneration, determining the source of seed if additional regeneration was required, and also deciding if site preparation was required.

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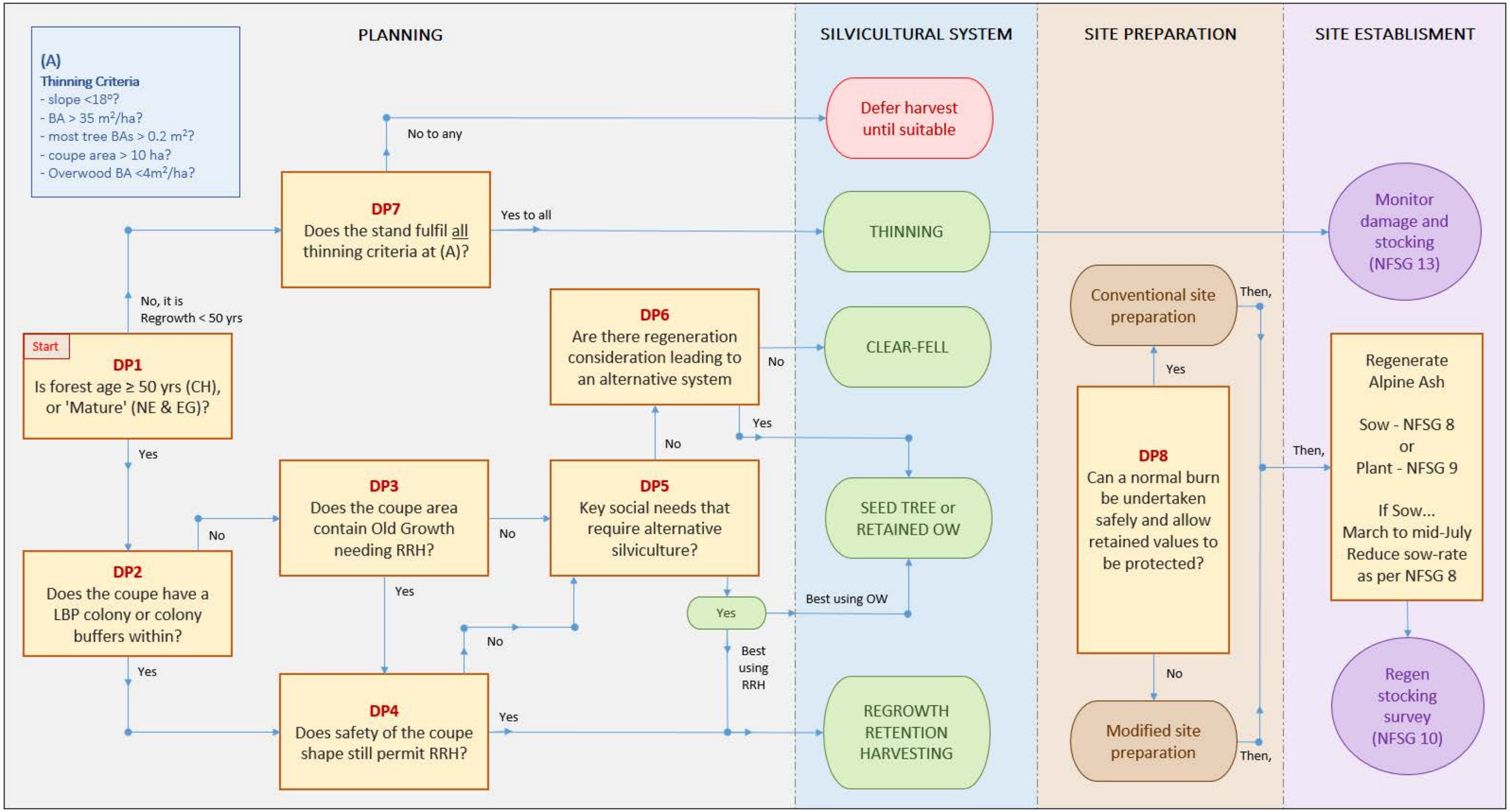

Figure 98. Decision Support System used in the past for selecting silviculture system when harvesting timber from Alpine Ash forests. OW = Overwood. RRH = Regrowth Retention Harvesting (a form of Variable Retention silviculture). Based on VicForests' DSS for silviculture (adapted from VicForests 2008). A stocking survey is required after site establishment (Bassett *et al.* 2014).

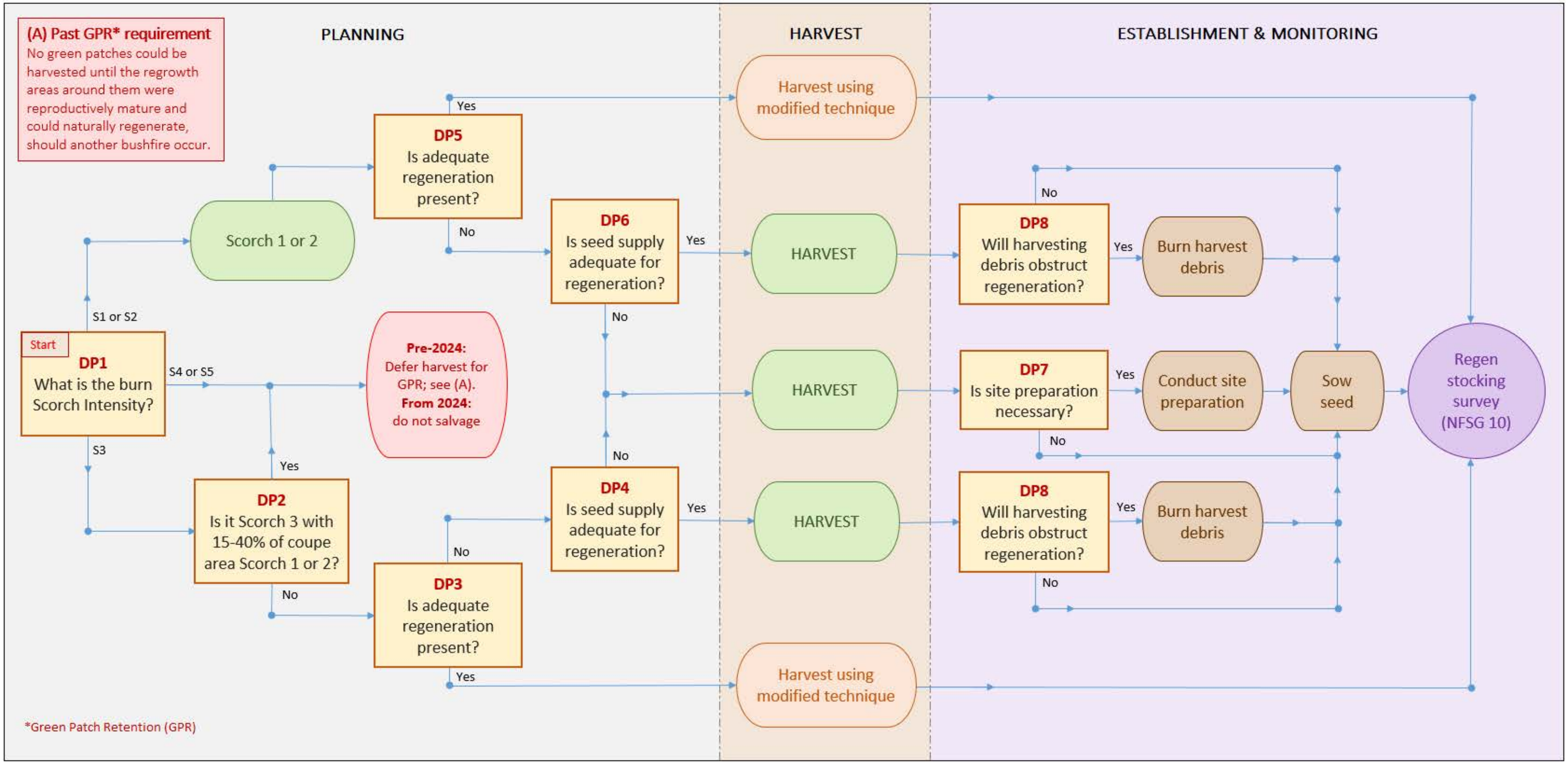

Figure 99. Decision Support System for deciding whether to undertake Salvage Harvesting, or not, and under what circumstances. The decision points relate to post-bushfire timber harvesting prior to 2024. Note that the removal of wood fibre, using salvage harvesting silviculture, may occur in the future as an active forest management tool to aid forest recovery following disturbances (see **Chapter 6**). GPR stands for 'green patch retention' (**Section 5.5.4**). For definitions of Scorch Intensities 1-5, see **Table 17**, **Section 7.4.3**. This diagram is a revised version of VicForests' DSS for Salvage. (Adapted from VicForests 2008). A stocking survey is required after salvage (Bassett *et al.* 2014).

6. Active management of Alpine Ash forests

At a time when there is limited information available on the topic, we acknowledge and thank Dr. Lauren Bennett (University of Melbourne) for allowing us to summarise and integrate her research on Active Forest Management into this Chapter.

6.1 Defining 'active management'

The use of the term 'active management', in the context of native forest management, has increased in the last 10-15 years, particularly in Victoria. The term has recently appeared in high-level policy documents authored by the Victorian Government, such as the renewed Regional Forest Agreements (State of Victoria, 2020). The term has also appeared in strategic documents by Traditional Owner groups (DJAARA 2022, 2017), outlining their objectives for 'care and management of Country', for which others recognise as being linked to *the* original form of active human interaction with forests in Australia (Keenan *et al.* 2021). The professional association of forest scientists and managers in Australia[49], and its members, have recently articulated their position regarding the "active and adaptive management of forests" within a framework of ecologically sustainable forest management (FA 2022, 2023). Their position was earlier articulated by Jackson *et al.* (2021), who proposed a detailed meaning of 'active management', reflected in their following summary statement:

"Active management includes reducing threats to forests, preparing forests for future threats, maintaining the capacity of forests to recover after disturbances, and restoring forests that have been degraded."

During Victoria's post-2020 bushfire era, a number of professional forest scientists also contributed to the 2021 Major Event Review (MER) as part of Victoria's review of Regional Forest Agreements (Bartlett *et al.* 2022). The resulting Forestry Australia submission recognised the work of others, including Traditional Owners, and identified the need for an active and adaptive approach to forest management, given recent impacts and declining condition, with some change to forest composition, structure and function[50]; including in Alpine Ash forests (Keenan *et al.* 2021).

However, despite its increasing use, the meaning of 'active management' is not clear and requires better understanding. For example, is it an aspirational term, seeking to reassure communities that forest management will be active and responsive to changing conditions or threats? Or does it refer to operational protocols and practices, providing on-ground guidance to forest managers (Bennett *et al.* 2023)?

In 2023, researchers from the University of Melbourne more recently reviewed 'active management' in temperate forests, examining how the term is used in the peer reviewed literature (Bennett *et al.* 2023). Their review found that practices most commonly associated with active management in temperate forests were based on the

[49] Forestry Australia (FA), formerly the Institute of Foresters Australia (IFA).

[50] Professor Patrick Baker (University of Melbourne) presents an excellent summary of the benefits of silviculture to the Royal Society of Victoria. Viewable at: https://www.youtube.com/watch?v=gRVJWXt__Vo&t=32s (accessed 10/04/2024).

application of a silvicultural strategy, with a focus on ecological thinning, prescribed fire, and activities which remove weeds and other undesirable species. To further progress discussion on the term and its use, the reviewers are developing a refined definition of active management (Bennett *et al.* in review), containing two conditions:

1. Active management is humans deliberately tending a forested landscape by implementing practices to maintain and/or modify composition, structure, or function towards a diverse range of potential purposes and goals; and
2. Active management sits within broader frameworks which enact the overarching philosophy, paradigm, and desired outcomes of the forest manager.

These two components highlight that active management refers to *human practices* and that these practices occur in a *broader operational framework* where the goals of the active management are defined.

This definition also makes specific and intentional use of the term ‘tending’ to reflect ongoing interaction and care by humans, rather than ‘intervention’ or ‘manipulation’ *“which may evoke more approaches that present humans as external to, rather than part of, the forest system*” (Bennett *et al.* 2023). This definition therefore allows space for forest managers and organisations such as government, Traditional Owners, and community forest management networks to engage actively with forests. Those wishing to benefit from ecosystem services and resources can engage within this system.

Following the arrival of Europeans to Australia, timber harvesting and applied silvicultural practices became a major scaffolding on which humans interacted scientifically with State forests in Victoria (**Sections 2.2 & 2.3; Chapters 3, 4 & 5**). The resulting experience and knowledge of foresters, forest scientists, technicians and industry personnel enabled them to also actively assist with the management of forests across all tenures; such as managing bushfire (e.g. McCarthy *et al.* 2003), applying thinning to achieve non-timber outcomes (e.g. Pigott *et al.* 2008) and recovering disturbed forest in National Parks (**Section 2.4**; e.g. Bassett *et al.* 2015), private forests (e.g. Bassett & Robinson 2010; Bassett & Whiteman 2012), and also managing non-timber values in State forests (e.g. VAA 2017).

Given the ongoing relevance of silviculture to tending forest composition, structure and function, and therefore to ‘active management’, it is appropriate that this Silvicultural Reference Manual considers what the future application of active management in Alpine Ash forests could look like, particularly in the context of the cessation of commercial timber harvesting in Victoria. As articulated by Keenan *et al.* (2021);

“*Silviculture can work to restore and enhance forest values, health, and resilience in the face of climate change, including the associated impacts of increasing drought, more frequent and shorter-interval bushfires, weeds, feral animals and disease”*.

In the following sections, we consider how the definition of active management could be applied to Alpine Ash forests, by first considering the broader position of active management when managing forests, then considering the practices which could support active management objectives, with the learned forest science presented in **Chapters 3 & 4**, and the practices presented in **Chapters 5 & 7** of this Manual.

6.2 What could active management look like in Alpine Ash?

6.2.1 Positioning active management into the future

How humans can continue to actively manage Alpine Ash forests beyond 2024 depends on the overarching policy, goals or objectives that exist for the Alpine Ash estate and the broader forest ecosystem in which Alpine Ash occurs. If the management objectives seek to ensure that Alpine Ash forests continue to provide a range of values such as protection of biodiversity, carbon storage, water, floral resources for apiary, wood, recreational opportunities, and social capacity for regional communities, then these will shape the active management practices which seek to maintain or modify these values.

In their review of the definition of active management, Bennett *et al.* (2023) articulated the importance of an overarching 'path' in which active management is placed relative to other forest management concepts. This 'path' has four key components, which can be adapted and developed to suit a range of philosophies and outcomes; though note that Bennett *et al.* (2023) consider that, regardless of the overarching philosophy or outcome, active management is an inclusive concept that would retain its position in the operational framework. The four key components are as follows:

1) Philosophy: describing the overall vision, intent, aspiration
2) Paradigm: providing principles and guidance
3) Framework: the operational cycle where active management is placed
4) Outcomes: indicators and measures of success

An example of the above, developed by Bennett *et al.* (2023), is an 'Instrumental path' (**Figure 100**), and uses the following adaptive concepts;

- The philosophy of Sustainable Forest Management, which emphasises ecological processes to sustain the composition, structure, and function of a forest to meet society's diverse cultural, economic, and political needs;
- The paradigm of adaptive management;
- An iterative adaptive management framework which provides the operational grounding to assess, plan, implement through active management, and monitor the practices necessary to maintain healthy adaptive forests; and
- The outcome of "healthy adaptive forests", which are demonstrated to maintain vigour, organisation, and recover from shocks and disturbances.

The iterative adaptive management framework, where active management is located, has a number of steps (**Figure 100**). '**Assess**' defines the purpose and targets of a management program and how it aligns with the overarching philosophy of forest management, while the '**Plan**' step can involve strategic scenario development to consider the range of potential management actions over time. The '**Implement**' step is where active management occurs – where the planning and decisions of the prior steps are enacted and in-field forest practices are implemented (Bennett et al., *in review*). Following implementation is the steps of '**Analysis and Adapt**' and '**Share**', using monitoring and the sharing of findings to learn about and evaluate the success of active management, then modify future assessment and planning to further adapt.

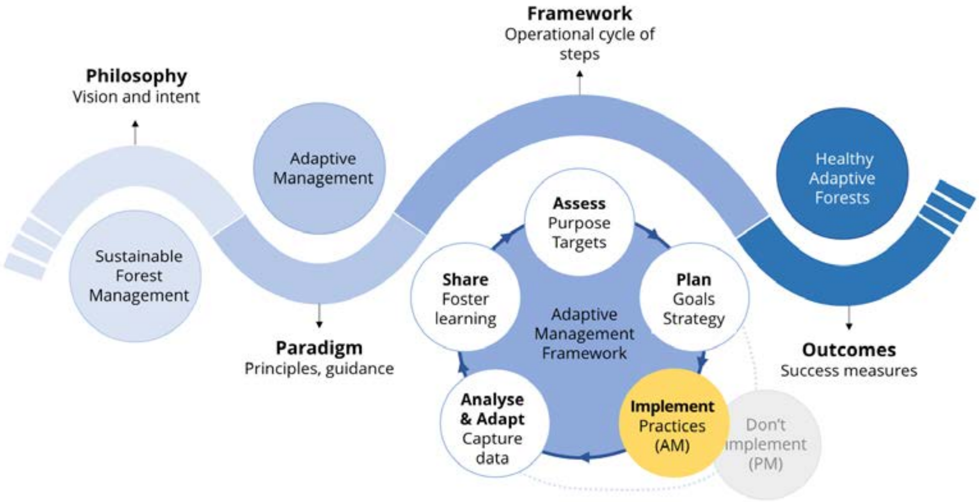

Figure 99. The "Instrumental Path" for forest management, included with permission from Bennett et al. (2023). This path positions Active Management ('AM'; yellow circle) as a key part of the Adaptive Management Framework which helps achieve the goal of 'healthy, adaptive forests'.

It is important that forest managers are able to place their active management efforts into a 'path' such as that described above, as understanding the intent and principles of forest management helps to frame the goals and outcomes which active management seeks to achieve.

The example path summarised in **Figure 100** is likely a useful template for the management of Alpine Ash forests; in which case, the philosophy remains sustainable forest management but the outcome is adjusted to 'healthy adaptive Alpine Ash forests'. The following Section discusses potential active management practices for sustainable forest management, and the sections of this Manual where more information can be found about these practices. It's imperative to recognise that, although commercial timber harvesting is no longer practiced, the past use of silvicultural systems to produce timber products, and knowing how Alpine Ash forest responds to them, holds invaluable learning for ongoing 'active forest management'. As such this Manual includes the science and application of all Ash silviculture.

6.2.2 Active management practices in Alpine Ash forests

The practices which make up active management in Alpine Ash forests are ultimately dependent on the broader framework and outcomes of strategic forest management. It is difficult to prescribe a single set of practices as representing 'active management' in the absence of knowing the future goals of forest management as, at the time of writing, Victoria is still in the transition period away from industrial scale, commercial timber harvesting. These goals will likely also change depending on the spatial context of the Alpine Ash forest under discussion and the broader forest policy that is expected to evolve.

This section presents an overview of active management practices for forest managers to consider as part of their planning for sustainable forest management. The outcome of 'healthy, adaptive Alpine Ash forests' is used here as the goal of sustainable forest management – that is, Alpine Ash forests which are resilient and adaptive to disturbance and climate change, and so able to maintain health, vigour and composition, and naturally restore their structures and forest functions in most scenarios.

A range of active management practices are considered which may assist with meeting these goals when applied in an adaptive management framework, and are linked to sections of this Reference Manual where detailed information on that practice can be found.

Table 14 provides information on potential active management practices available to forest managers, listed by distinct types and categories that generally align with the definition of active management; that is, silvicultural practices that **maintain** or seek to **modify** forest **composition**, **structure**, and/or **function**. The location of each silvicultural practice in the Manual is listed for easy reference.

The Alpine Ash forest estate in Victoria is currently spatially diverse with respect to state of health, structural integrity, and vulnerability. Impacts within the last two decades, such as increasing fire frequency (Fairman *et al.* 2016), the presence of high density, single-age and reproductively immature post-timber harvesting regeneration (Bassett *et al.* 2015; Bassett *et al*. 2021, Fairman 2022), and the presence of backlog regeneration following past timber harvesting (Bassett *et al.* 2014a) has, or will in the future, create a diverse mosaic of altered forest structures that represent a range of potential forest restoration opportunities.

Specifically, there are two silviculture systems that are transferable from a timber harvesting context to the new 'active management era', and which could align with the definition of 'Continuous Cover Forestry' in live forests[51]:

Thinning: *Comes in various forms suitable for stewardship; such as, uniform thinning, thinning from above, and thinning from below. The thinning objective is to reform forest structure to favour certain tree bole-sizes or dominance classes to achieve objectives that relate to improving forest health, increasing the rate of biodiversity development, enhancing understorey flora, increasing resilience to bushfire, and increasing water production (for past systems developments, see* ***Sections 5.3.1 and 5.3.3****).*

Selection: *Comes in various forms suitable for stewardship; such as, single tree selection, tree selection in small groups of 2-4 trees, and group selection to create gaps within which new regrowth can be regenerated. The selection objective is to modify forest structure to favour certain bole sizes or to input young regeneration to restore species composition, age class distribution, or crown architecture to enhance flowering and/or seed production. Enhancing flowering can increase natural seed capacity for*

[51]Continuous Cover Forestry is an international silvicultural system recognised by IUFRO11 (IUFRO 2002; Pommerening & Murphy 2004) and is characterised by selection harvesting and has inputs of natural regeneration. The system has already been trialled in dryer forests in Victoria to manage non-timber values such as apiary (VAA 2017, 2018).

forest restoration after disturbances, and provide increased nectar sources for fauna and honey bees where compatible. This system enhances structural diversity, supporting a multi-age structure that has relevance to Alpine Ash forests, as demonstrated in New South Wales (see also **Section 5.4**).

Table 14. A summary of potential active management outcomes and silvicultural practices and knowledge available to achieve the broader objective of healthy and adaptive Alpine Ash forests. Also refer to **Table 9** (**Section 5.4**) for a full summary of silvicultural systems suitable for Alpine Ash forests. "Ch." = Chapter.

Type	Category	Active Management practices	Knowledge and practices described in this Silviculture Reference Manual
Maintain	Composition, Structure & Function	• Protect climate refugia of Alpine Ash • Monitor forest function aspects like flowering, seed availability, tree growth, forest health & vigour, and biodiversity	• Ecology **Ch. 3** • Silvical Features **Ch. 4** • Restoration **Ch. 7**
	Composition	• Restore/reforest Alpine Ash after severe or repeat disturbance(s) • Regeneration after timber harvesting • Recovering backlog regeneration • Collect seed to assist restoration and support regeneration practices	• Silvical Features **Ch. 4** • Silvicultural Systems **Ch. 5** • Restoration **Ch. 7**
	Composition, Structure & Function	• Prescribed burning in adjacent dry forests to minimise bushfire impact • Bushfire suppression or exclusion • Remove post-fire or wind-damage overhead hazard risks	• Restoration **Ch. 7** • Wood salvage **Ch. 5**
Modify	Composition	• Promote or introduce climate adapted genotypes via planting or seeding • Restore known natural eucalypt species mixes not currently present.	• Silvic Features **Ch. 4** • Silvicultural Systems **Ch. 5** - thinning and gap Selection silviculture • Restoration **Ch. 7**
	Structure & Function	• Reduce the density of dense stands to within EVC benchmarks and encourage crown/habitat development, increase fire resistance, increase water production, and improve habitat • Restore healthy age-class and size-class distributions, where altered, to maintain/restore ecosystem health, vigour and diversity	• See Silvicultural Systems **Ch. 5** - thinning and gap selection silviculture • Restoration **Ch. 7**
	Structure & Function	• Alter planting densities and sow rates to encourage planned forest structural and/or functional outcomes • Reduce high density stands to encourage habitat development, fire resistance, enhancing water production, and for restoring floral resources and reproductive capacity	• Ecology **Ch. 3** • Silvic Features **Ch. 4** • Silvicultural Systems **Ch. 5** - thinning, gap selection and wood salvage silviculture • Restoration **Ch. 7**

Both these systems align with ‘Continuous Cover Forestry’, and could be adapted to achieve a new Australian system designed for active management with an explicit continuous canopy-cover objective, helping to distinguish active management practices from those with a timber objective. Although some trees may need falling to achieve stewardship objectives, with an option for removal for fuel management, the system by definition retains a continuous presence of trees across the forest, with a high level of canopy cover and no break to the critical forest functions typical of mature eucalypt forests. This forest management system, undertaken in conjunction with the State government, can be inspected in high elevation mixed forests located in both the Strathbogie and Toombullup ranges of NE Victoria (VAA 2017, 2018).

As such, ecological thinning could also be considered for maintaining a continuous cover objective, but only while maintaining, say, a uniform minimum 70% of original canopy cover, and not at thinning levels historically used for timber production. Other specific forest management objective may impact ‘continuous cover’. For example, thinning for water production or fire resilience may require a higher level thinning, potentially breaking continuous cover. A prescription for such new silviculture needs development.

A third silvicultural system may assist restoration following forest disturbances:

Wood Salvage: *Remove a defined density of standing or fallen Ash trees killed by disturbances such as bushfire or windthrow. For forests near roads or settlements, wood salvage makes the site safer for humans, provides a seed collection opportunity if windthrown, and can benefit the recovery of the disturbed site by improving regeneration capacity. Such an operation should be integrated with other forest recovery operations. Removed tree stems could be a source of wood for communities nearest the operation.*

It is envisaged that the full range of practices in **Table 14** would be integrated and applied across the landscape in achievable units of management, according to the silvicultural needs of each unit, considering the context and needs of neighbouring forest types as well, and responding to a strategic plan designed to fulfil the State’s sustainable forest and fire management objectives.

The in-field application of these active practices, to manage the needs of a dynamic Ash forest estate in a time of rapid change, is expected to provide real benefits to regional communities in the form of employment, social capacity, and to also benefit ecosystem services critical to human flourishing.

The question of whether the Victorian community has the capacity to undertake these aspirations is real and reasonable. It is notable that Bartlett *et al.* (2021) concluded in their Section 2.5 on active, adaptive and accountable forest management;

“*Victoria demonstrated its capacity to implement active and adaptive actions following the 2019/20 bushfires. These actions included the application of the precautionary principle in relation to timber harvesting in bushfire-affected areas, the implementation of enhanced immediate protection measures for threatened species, and the Ash forest restoration program, that treated 11,587 ha of fire-affected young Ash forests within State forests and National Parks”* (**Figure 101**).

Figure 101. Rowhan Marshall (when with Forest Solutions, and previously DEECA) inspects a successfully sown and established Alpine Ash forest in the Upper Dargo, 3½ years after the 2020 bushfires. The forest had also burnt after the 2006/07 and 2013 bushfires (triple burnt), giving rise to the IFKAR that the 2020 bushfire killed, and which could not naturally regenerate.

Regardless, the capacity to actively respond will always be limited by resources, as was the case, for example, after the 2019/20 bushfires (Bassett *et al.* 2021). However, such limitations can be minimised by immediate and rapid development of active forest management principles and programs that seek to grow community capacity for forest stewardship and ecosystem services, and meet the forest management demands expected to evolve in the new post-timber industry era.

7. Alpine Ash Forest Restoration

The increasing rate of disturbance of forest ecosystems, particularly in temperate regions of the world due to global changes in climate, emphasises the need for active forest management to restore key forest attributes that are compromised or eliminated by increased disturbances (Millar *et al.* 2007). The restoration of these attributes is likely to have positive outcomes for entire ecosystems, including biodiversity, habitat, carbon, water, and forest products of commercial or utilitarian value. In Victoria, the extensive and severe disturbances of the past two decades that have affected the native forest estate, predominantly in the form of bushfires (**Figure 102**), and more recently windstorms, have resulted in increased discussion of forest management and restoration approaches (Bassett *et al.* 2015b; Keenan & Nitschke 2016; Bowman *et al.* 2021). Restoration in Victoria has generally focused on Ash-type forests, and Alpine Ash has, in particular, required the most attention (**Figure 103;** also **Chapters 2 & 3**). The sudden decrease in fire return interval, with more mature Ash forests fire-killed each time and transitioning to immature stands that cannot recover on their own should another fire return at short-interval, is very concerning (Keenan & Nitschke 2016).

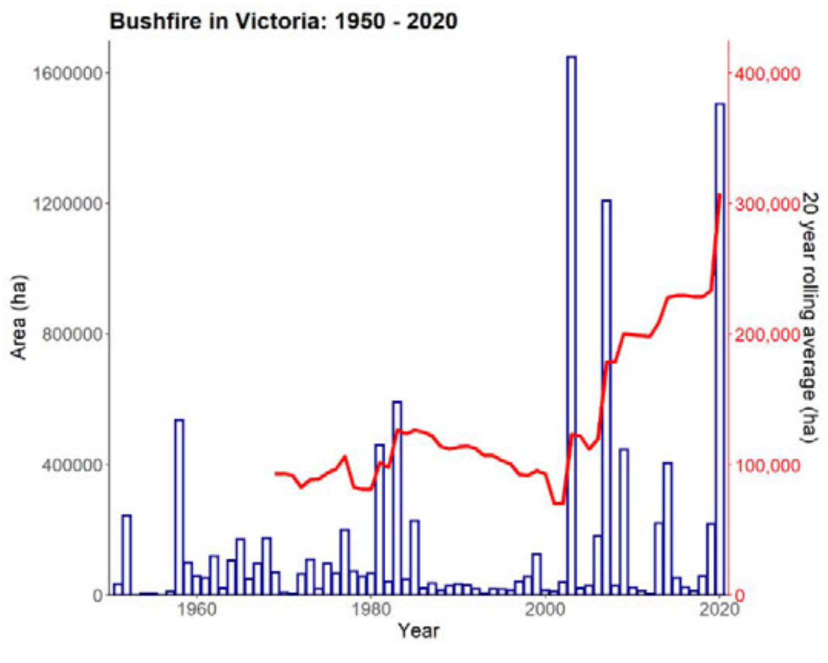

Figure 102. History of total area burned in bushfires in Victoria, 1950–2020. The red line represents the 20-year rolling average, and the series of large fires between 2000 and 2020 have elevated this to an average of 300,000 ha/year, at a frequency average of about 4 years. The authors acknowledge that recent wet years in Victoria, 2021-2024, bring the 20-year rolling average down, given 2003 would not be included. It remains to be seen if drought years and bushfires return to the same frequency.

This Chapter discusses the restoration context for Alpine Ash forests (**Section 7.1**), outlines the scenarios in which Alpine Ash may become degraded and require restoration (**Section 7.2**), discusses the potential goals and objectives of Alpine Ash restoration (**Section 7.3**), explores approaches to artificial forest recovery following short-interval disturbances like severe fire (**Section 7.4**) as well as reforestation approaches (**Section 7.5**), and summarises how the performance of restoration activities is monitored (**Section 7.6**).

Figure 103. Airborne: Extensive areas of short-interval bushfires in Alpine Ash exist in the Victorian Alps. The dead, white spars were live mature Alpine Ash fire-killed in 2007, and the red-brown or blackened dead regrowth, which resulted naturally from the 2007 fires, were then fire-killed in 2020 by high intensity fire. In the absence of human intervention, the species could be locally extinct at this location. Inside the 2020 bushfire footprint, there was about 25,000 ha of this (Bassett *et al.* 2021). Such a scale of damage poses a major dilemma for forest managers in Victoria.

As the area of immature Alpine Ash forest increases in Victoria, the species has become subject to the process of '**type-change**', which is broadly defined as a forest stand that has had its cover of Alpine Ash eliminated or seriously changed in species composition. This usually occurs when an immature Alpine Ash regrowth forest is fire-killed before it can reach its reproductive age (nominally 20 years, see **Chapter 3**). Historically in Victoria, Ash regrowth has usually established due to regeneration operations following timber harvesting (Fagg *et al.* 2008), or as the natural outcome of disturbances such as infrequent bushfires (Theobald & Lawlor 2006). It is now the more frequent occurrence of short-interval bushfires that causes more immature regrowth and increases the risk of type-change, currently occurring in Victoria after a secondary or tertiary fires with an average return interval of about 4 years as at 2020 (Bassett *et al.* 2021). The extent of type-change can vary from localised stands to landscape-level forests, and will depend on the extent of vulnerable forest present and the severity and extent of the short-interval fire. Vulnerability is ultimately caused by a lack of sufficient, viable seed being naturally available in regrowth/tree crowns. As stated, this is usually an issue of tree immaturity. However, in some years there may also be a paucity of seed in older age classes, including mature forests, depending on the recent history of flowering intensity, success of seed set, and seed crop ages present (see **Chapter 4**).

Human intervention, irrespective of land tenure, is an option if a local collapse of population is predicted during post-fire damage assessments. Given the extensive scale and issue this presents forest managers, it dominates much of this chapter, exploring the following:

(i) Key assessment steps and information requirements

(ii) Factors to consider when prioritising which forests are a candidate for recovery; and

(iii) Information on monitoring recovery efforts.

More broadly, this chapter emphasises active forms of forest restoration and recovery, rather than passive management which largely relies on the creation of reserves which do not address type-change and other forest issues (Carey 2003; Holl & Aide 2011; Lindenmayer *et al.* 2013; Poynter 2018; Lindenmayer & Taylor 2020).

7.1 Context of forest degradation and forest restoration

7.1.1 Defining key terms and concepts for forest restoration

Forest restoration uses a wide range of forest management approaches and activities to restore degraded forests. Degradation can occur due to a range of potential processes, such as land conversion, unregulated resource extraction, failing first-attempt regeneration following timber harvesting, severe disturbance, or pest and diseases. The management objective is to improve forest composition, structure and/or function towards a more 'natural', historical, or pre-determined endpoint which serves as the desired goal (Stanturf 2005; Stanturf and Madsen 2002).

Central to forest restoration is the concept of a **degraded** ecosystem. While forest degradation can generally refer to the reduction of a forest's capacity to provide goods and services (UN FAO 2011), this falls short of recognising all forest values by attributing priorities to only certain ecosystem services (Ghazoul *et al.* 2015). For example, a forest ecosystem with scattered large and damaged overstorey trees may be considered 'degraded' from a timber production perspective, but from a biodiversity perspective may hold valuable habitat for a range of species.

A more useful way of defining a forest as being degraded is whether it cannot naturally recover to its pre-disturbed state without human intervention (Ghazoul *et al.* 2015); that is, whether the process of vegetation succession will ultimately lead to a restored or 'non-degraded' condition. This definition is useful for fire-dependent forest types like Alpine Ash. It means that infrequent severe fires do not represent the 'degradation' of a mature Alpine Ash forest, even though that forest could be killed, given natural post-fire succession will usually enable ecosystem recovery within decades. Other disturbances, such as frequent fire at intervals shorter than reproductive age, or certain land management practices, may alter or arrest this successional pathway, triggering the need for restoration (see **Section 7.2**).

Stanturf *et al.* (2014) identified four general forest restoration strategies:

- **Rehabilitation:** restoring desired species composition, structure, or ecosystem function to a degraded ecosystem.
- **Reconstruction:** restores native plant communities on land recently in other resource uses, such as agriculture.
- **Reclamation:** restores severely degraded land generally devoid of vegetation, often the result of resource extraction, such as mining.
- **Replacement** of species or their locally-adapted genotypes, with new species or genotypes, as a response to climate change.

Of these four strategies, the most relevant to Alpine Ash forest is **rehabilitation;** though, as will be discussed in **Section 7.3**, it is possible that **replacement** may become relevant in certain future circumstances. **Rehabilitation** includes a range of tools and process, including silvicultural treatments designed to restore structural and compositional complexity.

We introduce here and define two additional subset forms of rehabilitation - **forest recovery** and **reforestation** (**Figure 104**).

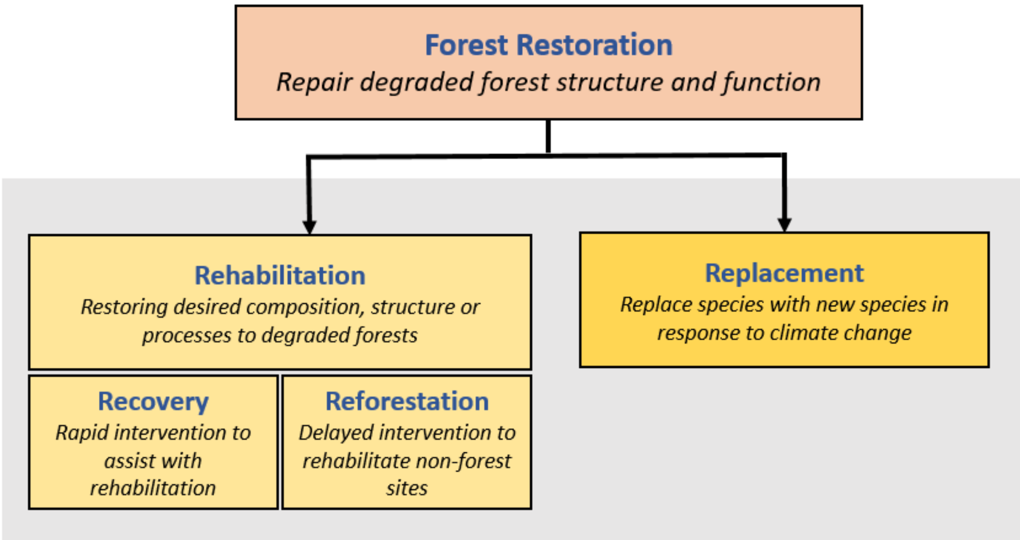

Figure 104. Forest restoration of Alpine Ash forests - understanding terms. These concepts are explored more in Stanturf *et al.* (2014), with aspects of recovery detailed in Poynter *et al.* (2009) and updated and refined in **Section 7.4** of this Manual which represents the latest systems employed to achieve forest recovery in Victoria's Ash forests.

Forest recovery represents a form of rehabilitation that is activated after severe disturbance, where it is identified that a forest is at risk of imminent population collapse. Forest recovery employs rapid intervention to make use of a 'window of opportunity' to reverse forest degradation and reinstate key ecosystem structures and functions. For example, the presence of a seedbed receptive to seed, which has reduced competition prior to site colonisation by pioneer species, presents a window of opportunity for sowing Alpine Ash seed.

Reforestation is another form of rehabilitation, designed to reconstruct a degraded forest by reintroducing key compositional features, such as an overstorey species like Alpine Ash, when significant time has passed with the forest in a continuous degraded, or even non-forest, state.

7.2 When do Alpine Ash forests require restoration?

The form of restoration required for Alpine Ash forests will vary depending on the context of the degradation (**Figure 105**). This Section summarise a range of scenarios, and they appear in order of the expected relative frequency of occurrence. Note that following this in **Sections 7.3**, **7.4** and **7.5** the Manual focuses predominantly on the goals and approaches of undertaking forest recovery of immature forests killed by severe fire, and reforestation of long-degraded stands, given the scale of these two issues for forest managers in Victoria.

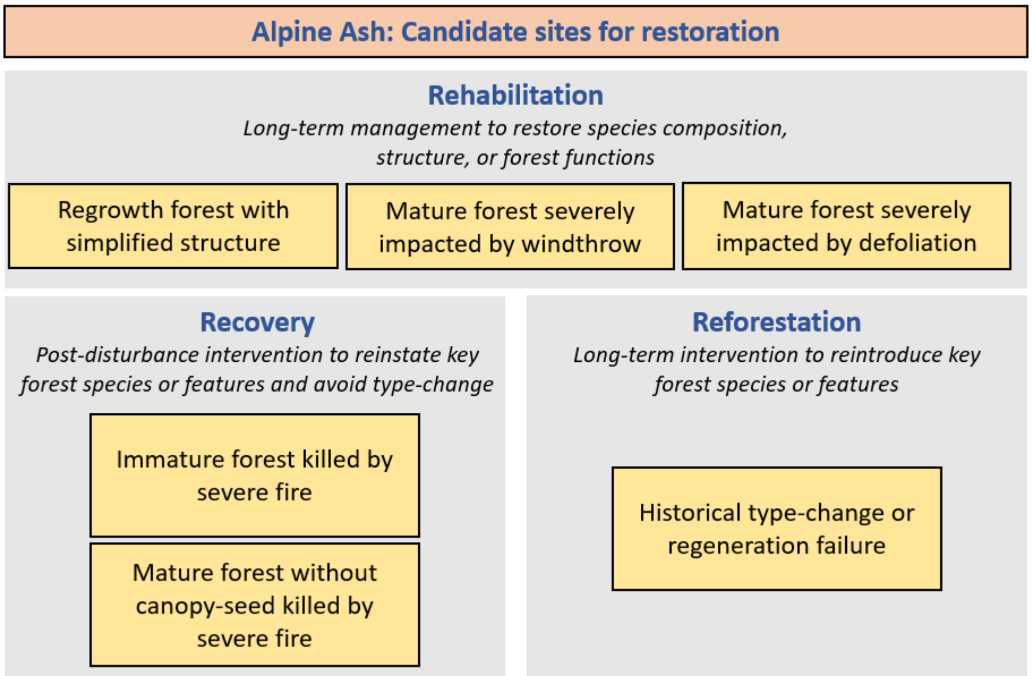

Figure 105. Summary of scenarios in which Alpine Ash becomes a candidate for restoration activities (rehabilitation, recovery or reforestation). Each of these scenarios are discussed in this chapter.

7.2.1 Immature Alpine Ash forest killed by severe fire

How this occurs: Immature regrowth is killed prior to reproductive age (<20 years), either as a result of multiple, short-interval bushfires, or if a bushfire kills artificial regeneration established following timber harvesting (**Figures 103 & 105**).

Recommended Restoration approach: Recovery

Background and details: Alpine Ash is vulnerable to 'immaturity risk'. When young, immature Alpine Ash stands regenerating from previous severe disturbance, such as bushfire or stand-replacing harvesting, are then impacted by a subsequent high severity fire, they are usually unable to regenerate given a lack of available seed, being too young to set adequate seed crops (See **Chapter 3** for more details). This, in combination with Alpine Ash's limited capacity to resprout after severe disturbance, could result in local extinction (extirpation), or 'type-change' (Bowman *et al.* 2014; Fairman *et. al.* 2016) which is the loss of the Alpine Ash forest type from a portion of the landscape (**Figure 106**). In areas where type-change occurs, the forest becomes dominated by mid-storey or understorey species which have persisted through the repeated disturbances. Species diversity may be reduced (Duivenvoorden *et al.* 2024). The exact species and life-forms remaining will depend on local site characteristics and on-site reproductive sources, but this may be Wattle or other shrub, Bracken and/or grass species (Bassett *et al.* 2015; Bassett *et al.* 2021). Other more fire-resilient, resprouter eucalypts, which were present in a mix with Alpine Ash, may also end up dominating the site if Ash disappears. Depending on the scale of immature ash forest and the subsequent severe disturbance, the extent of a patch of forest undergoing type-change may range from tens to hundreds of hectares; that largest in 2020 being about 500 ha (Bassett *et al.* 2021. Larger areas need priority, given smaller areas may naturally recover from neighbouring seed sources. Circumstances such as these represent a major risk to the ecosystem services that Alpine Ash forests provide (Lavorel *et al.* 2015), and type-change is the main reason why restoration is required.

Alpine ash forests undergoing type-change are also referred to as 'Immature Fire Killed Ash Regeneration' (IFKAR) (Fagg *et al.* 2013). Repeated fire is generally the most common cause of IFKAR. There is a long history of managing this issue in Victoria. One of the earliest examples of forest recovery after frequent severe fires was at Britannia Range near Warburton, where in 1926 a bushfire severely burned Mountain Ash forest, initiating stand-replacement and even-aged regeneration. This immature regeneration was burnt again in 1932 at age six years, leaving approximately 200 ha which failed to naturally regenerate. The site was direct seeded by hand in Autumn 1932, at a rate of approximately 0.3 kg per hectare (Powles 1940). In 1939 half of the resown area was then burned a third time in the well-known 'Black Friday' bushfires. The resown area which survived were of sufficient size to be harvested for timber in 1979 (Evans 1980)[52].

[52] Although, most 1939 Ash was not harvested for timber until the late 1980s once road networks were assessed and upgraded to support the significant increase in transportation of timber (Thomson 1988).

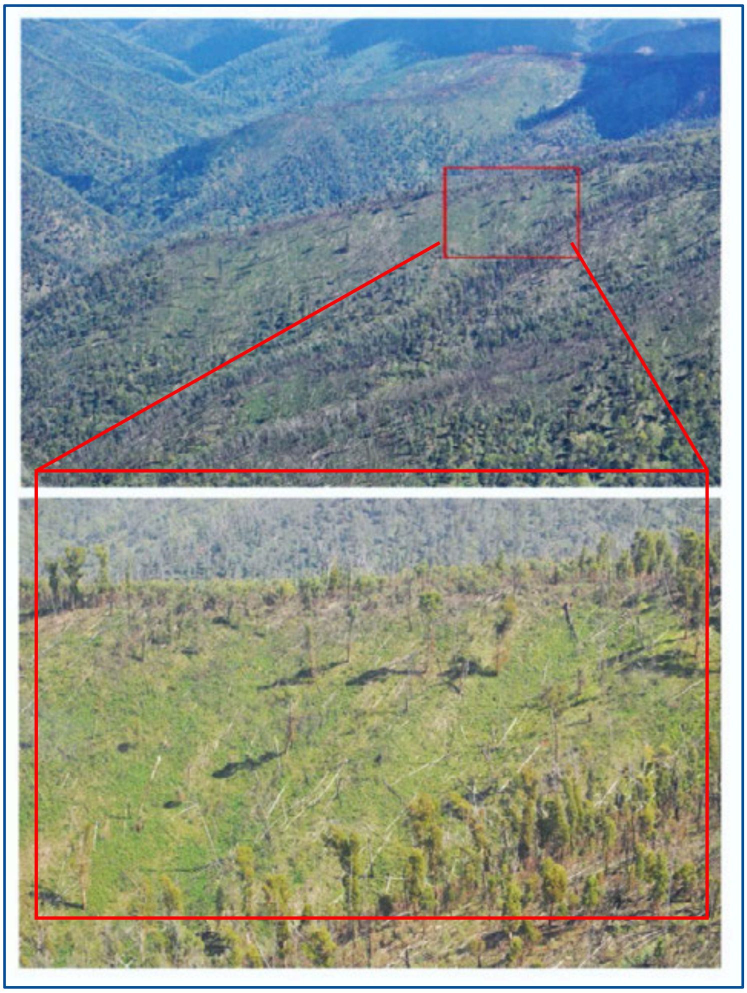

Figure 106. Type-change in a landscape context. Non-forest areas are former Alpine Ash forest which was burned in successive short-interval fires without recovery in the Alpine National Park, resulting in an appearance of 'bald patches' across the landscape. Note fallen dead white Ash spars from the original forest. Patchy resprouter eucalypts in the surrounding forest have persisted because of their vegetative capacity to naturally recover from epicormic buds (images: Tom Fairman).

Due to the extensive area of forest being burned by multiple, severe fires between 2003 and 2020 (**Figure 102 & 107**), post-fire forest recovery has become a regular feature of forest management in Victoria (Geary *et al.* 2021) (**Figure 108**). Over that time, the focus of forest recovery has evolved from the sowing of IFKAR which originated from recent timber harvesting in State forest (Theobald & Lawlor 2006; Fagg *et al.* 2013) to now also include the recovery of IFKAR in both State forest and National Park (Bassett *et al.* 2015b) to meet ecological objectives and maintain ecosystem function. The largest resowing program at the time of publication of this Manual was undertaken in Victoria following the 2019/20 Black Summer bushfires, sowing 11,500 ha of ash forest across State forest and National Park (Fairman *et. al.* 2021; Bassett *et. al.* 2021; Bartlett *et. al.* 2022) (see also **Chapter 3**).

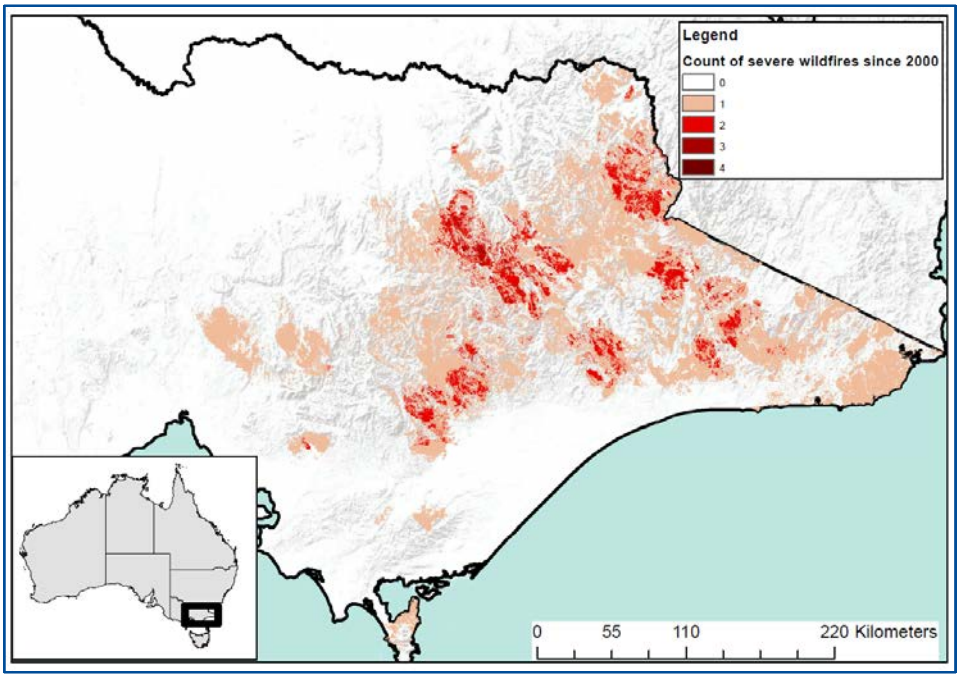

Figure 107. Extent of severe bushfires between 2003 and 2020. Note this illustrates the extent of all fires and does not represent the extent of Alpine Ash impacted by multiple fires. However, this fire extent accounts for about 90% of Alpine Ash in Victoria, with a growing proportion of fire-killed Ash, and a declining estate of live mature Ash remaining with every new fire. A concern is that a fourth mega-fire may leave little mature Ash remaining.

Assessment ability and data availability: Large scale desktop assessment of the general extent and severity of fire impact to Alpine Ash following a bushfire is straightforward. However, knowing where to sow Alpine Ash seed at the finer scale across the whole impacted landscape, and ensuring a source of stored seed to achieve this, is more complex (Poynter *et al.* 2009; Bassett 2011; Bassett & Fagg 2018; Bassett et al. in prep[53]; **later this Chapter**). A more detailed assessment of the forests' capacity to naturally regenerate is required, using silviculture specialists to undertake complex assessments based on remotely sensed and aerially acquired observations and imagery over large forest extents. For applied examples, see Bassett *et al.* (2015b), Bassett & Gailey (2018), Bassett & Gailey (2019) and Bassett *et al.* (2021). Capability exists through established partnerships between State government and private sector silviculture and aviation specialists.

Many data sources are available across DEECA and Parks Victoria. Data on fire history in Victoria's forests, including extent and severity, are widely available. University of Melbourne provides modelled data related to potential future fire and risk across Ash forests. Data availability on timber harvesting history and silviculture mapping are available.

[53] NFSG No. 2 *Seed Collection* (Wallace 1994) – version 2 currently being written, due by 2025.

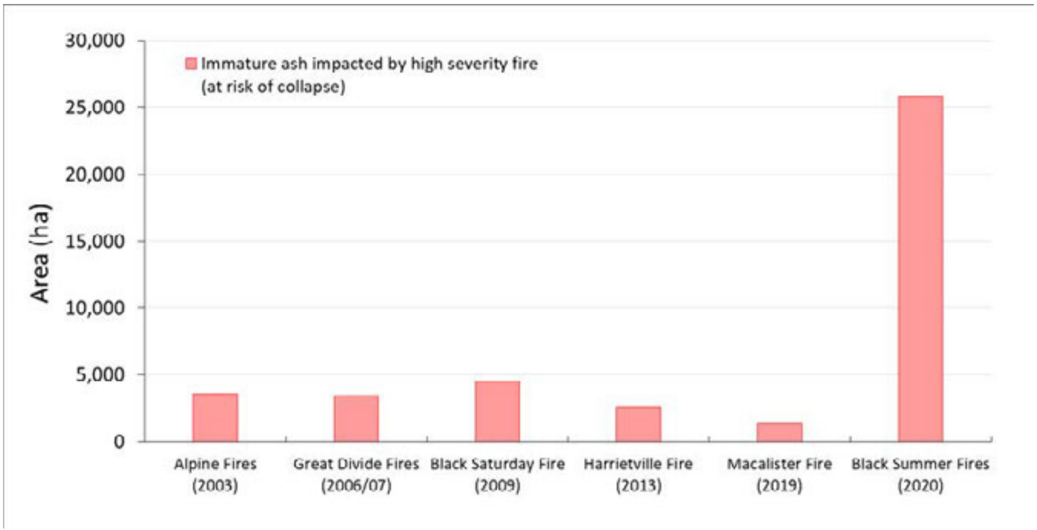

Figure 108. Extent of immature Ash forest, largely Alpine Ash considered now at risk, or which was for 2003 regrowth prior to its reproductive maturity in 2024, following major bushfire events over the last two decades, with return fire frequency averaging four years. The huge increase in 2020 was due to the presence of extensive regrowth present from the earlier fires. Data sources: Fagg *et al.* (2013), Bassett *et al.* (2015), Bassett & Gailey 2019, and Bassett *et al.* (2021).

7.2.2 Historical type-change or 'backlog regeneration' failure

How this occurs: Backlog regeneration refers to areas of Alpine Ash which have failed to successfully regenerate following historic timber harvesting, and have undergone type-change and become dominated by non-Ash vegetation for a long period of time (**Figure 105**).

Recommended Restoration approach: Reforestation

Background and details: Three distinct scenarios exist; (1) fire impacted forests, (2) backlog regeneration (timeframe long-term), and (3) failed 1st-attempt regeneration operations following timber harvesting (timeframe short- to mid-term).

(1) Fire impacted forests: There are substantial areas of Alpine Ash forest that were fire-killed by multiple fires in the 2000s, failed to naturally regenerate, and had no intervention undertaken to enable restoration (**Figure 106**). This has recently occurred for the following reasons, with examples provided:

(i) *Land management policy that does not allow for active intervention.*

Prior to 2013, Parks Victoria had no policy for intervention where Ash species were known to be at risk following bushfires. Consequently, all immature fire-killed Ash regrowth (IFKAR) within the Alpine National Park following the 2003 and 2006/07 bushfires is expected to have not recovered (Fagg *et al.* 2013). This changed from 2013, with Parks Victoria joining intervention efforts following bushfires in that year, again in 2018 (attempted, see point *(iii)* below), then 2019 and 2020 (Bassett *et al.* 2015; Bassett & Gailey 2019; Bassett *et al.* 2021). Refer to **Box 1, Section 2.4** for Parks Victoria's latest risk analysis and response to IFKAR.

(ii) Insufficient stored seed to sow all IFKAR

Storing sufficient seed to sow IFKAR areas that are receptive to seed is critical to active forest recovery operations (Poynter *et al.* 2009; Ferguson 2011; Bassett 2011). However, seed demand following recent bushfires has usually exceeded storage supply[54]. The most impactful example occurred in 2020, with a deficit of seed leaving about 8,400 ha of receptive area that needed sowing to be left unsown (Bassett *et al.* 2021).

Based on recent fire history and predicted climate change impacts, Ferguson (2011) recommended a Strategic Seed Bank be developed including a large store of Alpine Ash seed. An advised State government policy drafted in 2011, with assistance from Forest Solutions, sets a target of 23 tonnes (DELWP 2018), considering the Ferguson analysis and based on a 2018 seed management review by Bassett & Fagg (2018).

(iii) Forest management response is not rapid, leading to shortfall of available time.

For Alpine Ash, sowing to recover IFKAR is ideally completed prior to close June in the first winter following a bushfire (Poynter *et al.* 2009). Post-fire damage assessments, sowing plans, and the logistics of aircraft availability must be completed in time to enable a June-latest sowing. For example, a shortfall in planning time left insufficient time for sowing in 2018, resulting in 500 ha of receptive IFKAR being left unsown in the Alpine National Park (Bassett & Gailey 2018). While sowing directly onto ash or mineral soil is preferred, perhaps prior to major snowfalls, sowing onto fresh, shallow snow is acceptable as dark seeds become relatively ‘warm’, with potential to melt their way through fresh snow to the ground-level ash and/or soil layer (Jacobs 1955).

(iv) Seedbed not receptive to seed.

Not all IFKAR can be sown. Part of every post-fire damage assessment is an evaluation of how receptive to seed the seedbeds are for all IFKAR areas. Where fire severity is only light to moderate, but Ash still killed, seedbeds may be unreceptive due to persistence of live competition or unburnt litter layers (see **Chapter 4**). For example, about 5,600 ha of IFKAR was identified as unreceptive to seed following the 2020 bushfires, not recommended for sowing, and was therefore left unsown (Bassett *et al.* 2021).

(2) Backlog regeneration. There are areas of forest that were harvested for timber by the State government prior to 2004 and which are understocked following initial treatment, according to timber harvesting standards in the Code at that time. These have not subsequently been artificially regenerated, and are now known as ‘backlog regeneration’. Following assessments based on aerial photo interpretation, Bassett *et al.* (2014a) estimated about 4,500 ha of backlog remained understocked in Victoria. Given the window of post-disturbance opportunity to recover these forests have passed, reforestation is the only option for these areas. However, it is possible that

[54] 2003 was an exception, with a rapid collection of heavy seed crops in that year following an excellent 2002 flowering event (Bassett *et al.* 2002). About 1.5 tonnes was carried in store and used after the 2006/07 fires.

widespread bushfires over the last decade have re-burned some understocked areas and induced suitable natural regeneration (Bassett *et al.* 2021), at least to an acceptable ecological stocking standard (Bassett *et al.* 2014b). See **Section 7.5** for further discussion of operational considerations for this scenario.

(3) Failed 1st-attempt regeneration. In Victoria, during the six year period from 1993/94 until 2000/01, about 6,600 ha of Alpine Ash forest was harvested, treated and surveyed by the State government. About 5,500 ha was successfully regenerated at first attempt (Bassett & White 2003; Fagg *et al.* 2008). Second+ attempts, soon after the initial failure, are known as 'retreatments', but are considered reforestation here as a matter of definition, given the initial loss of site receptivity that would lead to type-change if left untreated. **Table 15** summarise the success rate in Alpine Ash forests for first attempt, retreatment and reforestation of longer term unstocked harvested areas.

Table 15. Summary of regeneration success for Alpine Ash following various restoration treatment types after timber harvesting in Victoria by the State government for the period 1993/94 to 2000/01. This data is pre-VicForests, who achieved similar or better results during the 2004-2018 period.

Restoration type	Area treated (ha)	Area stocked (ha)	Success rate (% of area)
first-attempt	6,618	5,449	83%
retreatment	214	78	36%
reforestation	43	32	74%

It's interesting to note that retreatment has a far lower regeneration success rate than first-attempt (**Table 15**). Aerial sowing is often used again during retreatment, and the exposed, soil-disturbed sites can be unfavourable to this form of establishment. In contrast, forest managers usually plant high quality nursery stock during reforestation, leading to the higher success rate listed for reforestation in **Table 15 (see Box 14)**.

Assessment ability, data availability: Areas of Alpine Ash 'backlog' (Bassett *et al.* 2014a) and failed retreatment regeneration (Fagg *et al.* 2008) are known, and areas of previous Ash forest predicted to type-change have been identified since 2013 (Bassett *et al.* 2015; Bassett & Gailey 2018, 2019; Bassett *et al.* 2021). However, there is no complete centralised database of confirmed type-change following short-interval fires. This is a major gap in State spatial mapping and requires an update via field investigation to confirm type-change outcomes or otherwise. Aerial photography is useful to estimate stocking of areas suspected of having undergone historical regeneration failure, but note this has only been used so far to estimate regeneration in contained areas such as harvesting coupes (Bassett *et al.* 2014a).

Box 14. Connors Plains Reforestation in 2010/11

An area of about 30,000 ha of Alpine Ash was burnt during the 2006/07 Great Divide fire (Jewel *et al.* 2008), including about 1,500 ha across Connors Plains, south of Mt. Skene. Approximately 90% of mature Ash forest was killed, with very scattered natural regrowth occurring due to a lack of canopy seed and other limitations (Bassett 2005; Fagg *et al.* 2013). To salvage timber and reverse the failure of earlier natural forest recovery, VicForests salvage-harvested about 1,100 ha (Sanders 2010), then undertook a major reforestation program, managed by Mr. Ian King and deputy, Mr. Bryan Nicholson. Harvested areas were soil disturbed using excavator-mounted root rakes to reduce competition, Snow Grass was treated with herbicide, and the area was then aerial sown or hand planted (**Figure 109**).

Figure 109. (Left) An eastern view from Connors Plains showing Alpine Ash type-change with Snow Grass (foreground) and soil disturbed seedbed (middle-ground). **(Right)** Mark Sheperd (VicForests) tags new germinants.

To gauge regeneration success, Connors Plain was stratified according soil type and dominant understorey vegetation type using vertical aerial imagery prior to site preparation. Germination plots were established and monitored to span two spring periods (**Figure 109**).

Reforestation was successfully achieved (Bassett *et al.* 2012) (**Figure 110**).

Figure 110. Airborne. A thousand hectares of 2007 type-changed, grass and wattle on Connors Plains successfully reforested back to Alpine Ash during 2010/11. This oblique aerial image was captured by Forest Solutions 10 years after establishment in 2021.

7.2.3 Regrowth forest with simplified structure

How this occurs: Following stand-replacing timber harvesting or severe fire, Alpine Ash regenerates prolifically in even-aged stands which may be too-dense and have an over-simplified stand structure (**Figure 105**).

Recommended Restoration approach: Rehabilitation

Background and details: While dense regeneration of Alpine Ash is generally normal after high-intensity disturbance, there can be wide variability in the density and pattern of regeneration particularly after natural disturbances like mixed severity bushfire (Trouvé *et al.* 2021b). Dense even-aged regeneration may prolong the development of desired forest structures and be vulnerable to subsequent disturbances (Franklin *et al.* 2002; Trouvé *et al.* 2021a). Where very dense regeneration of forests is identified and the more rapid reinstatement of a more heterogeneous forest structure, compared to natural self-thinning rates, is an objective of forest management, forest rehabilitation through active measures such as Thinning can assist in giving rise to more diverse and complex forest structures and possibly reduce fire risk (Burrows *et al.* 2022; Keenan *et al.* 2021; Stanturf *et al.* 2014).

Assessment ability, data availability: Data on Alpine Ash regrowing from severe fire or timber harvesting can be inferred from Victorian Government datasets. However, assessment of sub-optimal stand structures in these areas is not readily available and would require a more intensive approach. The authors encourage this form of active management.

7.2.4 Mature forest severely impacted by windthrow

How this occurs: Severe windthrow uproots Alpine Ash overstorey, and the resulting debris and crushed vegetation does not create a suitable seedbed for regeneration (**Figure 105**).

Recommended Restoration approach: Rehabilitation

Background and details: A severe windthrow event can cause the uprooting of Alpine Ash and hence the destruction of overstorey seed source. The seedbed is obstructed by fallen debris and crushed understorey species, leaving few opportunities for natural regeneration, likely leading to type-change. Recorded examples of this in Alpine Ash are few, but they indicate such events can be severe at the small scale (< 10 ha). Forest rehabilitation is appropriate in this scenario, where fire is applied months or years after the windthrow event to generate a suitable seedbed after which seed is applied. This method successfully regenerates Alpine Ash forests, even multiple years after the windthrow event. See discussion of windthrow in **Section 3.2.2**.

Assessment ability, data availability: Severe windthrow events are rare, and require aerial photography/assessment to map the impact at local and landscape scales. Remote sensing has been explored following the 2021 windstorms, but ground monitoring is required.

7.2.5 Mature forest killed in severe fire, without canopy seed

How this occurs: During a poor seed production season, a mature Ash forest with a limited seed crop may fail to regenerate naturally after a severe bushfire (**Figure 105**).

Recommended Restoration approach: Recovery or reforestation

Background and details: Consecutive poor flowering seasons can lead to a paucity of seed crops in mature Alpine Ash forests (See **Chapter 4**). If a forest in this state is subsequently burned by high severity fire, the lack of available seed in canopy leads to the risk of type-change. There are few recorded instances of this occurring. The most well-known example was following the 2006/07 Great Divide Fires, where a lack of canopy seed was extensive and led to poor regeneration outcomes in some parts of the Alpine Ash estate (Bassett 2005; Fagg *et al.* 2013; **Figure 55, Section 4.1.2**; see also **Box 14**). The annual forecast of Ash seed availability helps build an understanding of flowering behaviour and seed production across the landscape prior to each fire season (**Section 4.2**). Where fire-killed mature stands are known to have held insufficient seed, they can be listed as candidates for forest recovery where seedbeds are receptive (**Figure 105**). Where this type-change risk occurs, it may only impact localised parts of the landscape due to patchy flowering, such as expected for Alpine Ash in 2024/25 (Bassett 2023, 2024). This may mitigate much of the risk due to the potential availability of a seed supplies in neighbouring stands. However, impacts to large landscape level stands are possible. For example, a poor seed crop is expected for Mountain Ash in 2024/25, given several years of shortage already and another poor flowering year in 2023 and again expected in 2025 (Bassett 2023, 2024).

Assessment ability, data availability: Fire severity and growth stage data is available. Flowering and seed crop forecasting is annually undertaken by Forest Solutions Pty Ltd and used to assist forest recovery operations if a bushfire should occur.

7.2.6 Mature forest severely impacted by defoliation

How this occurs: Defoliation by biotic (insect attack) or abiotic (drought) drivers may result in canopy die back then tree death, with no suitable seedbed for regeneration (**Figure 105**; see also **Section 3.2.3**).

Recommended Restoration approach: Rehabilitation

Background and details: There are some documented examples of this occurring in Ash forests, such as when severe infestation of canopy defoliating invertebrates resulting in high overstorey mortality, particular after multiple infestations over a short period (e.g. biennial infestations of Phasmatids) (Neumann *et al.* 1977). In such instances, the overstorey is killed but understorey is not impacted, therefore preventing the regeneration of the overstorey eucalypt species. Where such instances occur at a large scale in Alpine Ash, forest rehabilitation may be required for regeneration.

Assessment ability, data availability: Mapping of canopy defoliation events has historically occurred for pest outbreaks using aerial assessment. Pre-emptive monitoring of pest species focusing on biological indicators, such as presence of Phasmatid eggs in litter, may support a predictive capacity for severe outbreak.

7.3 Setting goals for Forest Restoration in Alpine Ash

Alpine Ash is a keystone species in eastern Victoria's mountain landscapes, and the goal of restoring these forests impacted by, or threatened with, type-change is to maintain the species type and forest structures that provide multiple benefits for which they are valued; such as recreation, water production, timber production where allowed, carbon sequestration, habitat, or visual aesthetics. However, the actual goal of forest management can vary beyond these more obvious benefits, depending on current trends in factors like climate change and changing fire regimes.

There is currently a range of strategies for managing Alpine Ash forests across Victoria, given they occur in National Parks, alpine resorts, State forests, and other reserve systems within State forest landscapes. Consequently, approaches to restoration may differ by tenure depending on the forest management objectives of the landscape in question. Historically, timber harvesting has been practiced in State forests, highlighting this tenure as having different management objectives to National Parks, for example. Given timber production is no longer practiced[55], the land management objectives between tenures have become less polarised, supporting instead a shared active management approach across all landscapes and tenure boundaries. Indeed, some forest elements remain the same regardless of current tenure objectives, so can be restored using similar active management strategies, such as aerial sowing for post-fire forest recovery (**Figure 111**).

One immutable fact is that resources will always remain constrained, limiting the type and range of options available for restoration. Examples of limited resources include skilled human resources, stored seed ready to use, seed collection capacity, available aircraft capable of sowing seed, access to remote areas, spatial data sets, and machinery for on-ground operations.

At a higher level, forest restoration in the context of climate change and ecosystem instability may lead to a range of different approaches and goals (Cole & Young, 2010). For example, the National Parks Service of the United States has developed the 'R.A.D.' Decision Making Framework (Lynch *et al.* 2021; Schuurman *et al.* 2020) to assist land managers in making resource management decisions in the 21st century when confronted by rapid change. The framework proposes that land managers can apply any of three approaches to address ecosystem transformation that results from a changing climate or other drivers of change (Schuurman *et al.* 2020):

- *Resist* the trajectory of change, by maintaining or restoring ecosystem processes, function, structure, or composition based upon historical or acceptable conditions.
- *Accept* the trajectory of change, by allowing ecosystem processes, function, structure, or composition to change, without intervening to alter their trajectory.
- *Direct* the trajectory of change, by actively shaping ecosystem processes, function, structure, or composition towards desired new conditions.

[55] The State government of Victoria ended native forest timber harvesting in early 2024.

Figure 111. Airborne: an expanse of IFKAR across the Macalister landscape following the 2020 bushfires, dwarfing fixed-wing VH-LIS (lower centre) as it operated tenure-blind, sowing Alpine Ash seed onto State forest in the foreground and continuing left to right across Basalt North Track into the Alpine National Park, representing cross-tenure active management (image: Forest Solutions).

In the specific context of Alpine Ash, three climate change mitigation and adaptation approaches have been explored (Doherty *et al.* 2017b; Nitschke & Wagner 2021):

1) **Planned mitigation:** where forest managers maintain Alpine Ash forest structure and function based on the status quo (similar to '*Resist'* in the R.A.D. framework), such as when aerial sowing IFKAR to maintain species distribution.

2) **Planned adaptation:** where forest managers select a different future forest composition and structure, elevating species which are more resilient to changing fire regimes. This may include selecting non-ash eucalypt species, or particular provenances of Alpine Ash, in resowing or reforestation programs where Alpine Ash is impacted (similar to *'Direct'* in the R.A.D. framework).

3) **Autonomous adaptation:** where forest managers allow independent ecological processes to dictate forest composition. This may include allowing or maintain the transition of previously Alpine Ash forest to scrub or mixed species forests (similar to '*Accept'* in the R.A.D. framework).

Either the R.A.D. or mitigation/adaptation frameworks may assist forest managers in prioritising certain parts of the landscape and guiding future forest restoration efforts, especially in the context of climate change and changes in associated fire regimes (McColl-Gausden *et al.* 2021). These frameworks have been widely discussed in the scientific literature (Colloff *et al.* 2016; Doherty *et al.* 2017b) but integrating them into the frameworks of forest policy and operational forest management still need further development. Similarly, some datasets have been developed exploring these options for land managers in Victoria (Wagner & Nitschke 2021), but these also require further research, analysis and development.

Ultimately, the end goal of ash forest restoration needs to be fit-for-purpose, taking account of the local landscape, its current and future values, and management regime and objectives. Each of these will shape goals and the operational approach of forest restoration. **Table 16** explores some different hypothetical management regimes and objectives for Alpine Ash forests which have become degraded, and how these may shape restoration goals and approaches.

7.4 The forest recovery process after bushfire

Key stages and information requirements

There are three stages in the post-fire forest recovery process for Ash species. **Figure 112** presents a forest recovery framework that includes these three stages and summarises the key data requirements and outputs that support the recovery process.

1. Strategic Risk Assessments are undertaken by the Victorian Government's bushfire Rapid Risk Assessment Teams (RRATs), who are immediately deployed after bushfires to assess fire impact on all values and assets. This includes an early estimate for distribution of Immature Fire-killed Ash regrowth. An applied example is DELWP (2019b), for the Macalister Complex Fire. **See Section 7.4.2**.

2. Tactical Damage and Recovery Assessments are undertaken by the Tactical Silviculture Specialists (TACSSs) unit reporting to the Rapid Response Recovery team (RaRRe), using guiding techniques provided in Poynter *et al.* (2009)[56]. The TACSSs unit can consider the Stage 1 outputs, but they undertake a separate and more detailed analysis of fire damage to Ash forests and also directly assesses their capacity to naturally recover.

Recommendations for recovery action are provided, including priority areas for aerial sowing (**Section 7.4.4**). Applied examples are reported in Bassett & Pryor (2014), Bassett *et al.* (2015b), Bassett & Gailey (2019), and Bassett *et al.* (2021)[57].

The Operations unit has a role during Stage 2, refining the recommended priorities provided by the TACSSs unit (**Section 7.4.4**), using filters of modelled refugia, provenance, and forest values (**Figure 112**). See also **Section 7.4.3** for more details.

3. Operational Recovery and Monitoring is undertaken by the Operations unit nested in the RaRRe team. The TACSSs unit is also nested in the RaRRe team (**Figure 112**). The Operations unit draw on operational and silviculture specialists from other organisations such as University of Melbourne and the private sector[57] to assist with aerial sowing. This team also oversees seed supply, balancing immediate seed collection needs with current seed storage levels. See **Sections 7.4.4 and 7.4.5**.

Note that the **Figure 112** framework has been developed for IFKAR recovery, however can be generalised to other instances where there is a risk of type-change in Alpine Ash. While this framework flows from left to right, the process is adaptive, whereby newly acquired information in later steps can be fed back to refine earlier steps.

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[56] Native Forest Silviculture Guideline No. 17 *Forest Recovery after Bushfire*.

[57] Specialist private silviculture expertise is currently limited in Victoria. An expansion of skill sources, options and succession planning is required by 2030 (O. Bassett *pers. comm.*).

Table 16. Example of different management regimes and their relationship to forest restoration goals and approaches. Some regimes could be applied at the landscape scale.

Regime	Objective(s)	Restoration framework and goal	Restoration approach
Timber production	Provide for production of hardwood timber and other forest products (apiary, water, minor forest produce) alongside protection of natural, scenic, and landscape values	***Resist / Planned Mitigation*** Regeneration of alpine ash at high stocking to allow for good form (sawlog priority) and avoid type-change.	Undertake recovery or reforestation. Apply 'timber production' sowing rate of 125,000 viable seeds per hectare to achieve full site occupancy.
Maintaining ecosystem function	Protect the environment, biodiversity, structure and underlying ecological processes and functions	***Resist / Planned Mitigation*** Maintain a minimum viable ecological role of Alpine Ash as a component of ecosystem structure and processes, and avoid type-change.	Adjust recovery or reforestation procedures for site context. If sowing, use minimum sowing rate to ensure persistence of Alpine Ash as 'ecological stocking'. This may be 10% to 50% of timber production stocking[58].
Maintain refugia	Prioritise key Alpine Ash for protection in areas modelled to be refugia under future fire and climate regimes. Could accept type-change elsewhere.	***Resist / Planned Mitigation*** Prioritise the recovery of Alpine Ash stands which have been modelled to occur in climate and fire refugia.	Target recovery or reforestation to specific refugia in the landscape. If sowing, use minimum viable or moderate level of sowing to maximise likelihood of persistence of Alpine Ash in refugia.
Type-change	Accept short interval bushfires as natural and do not undertake interventions; allow development of novel forest and non-forest communities	***Accept / Autonomous Adaptation*** Allow type change to occur in Alpine Ash stands and allow for ecosystems to reorganise.	No recovery or reforestation intervention; monitoring of type-change to understand ecosystem trajectory and ecological communities which develop. Could maintain refugia (as above).
Assisted ecosystem transition[59]	Accept development of new ecosystems under climate change and actively intervene to assist in their development while maintaining essential forest ecosystem services	***Direct / Planned Adaptation*** Enable transition from local Alpine Ash to other species or to other Ash provenances which may be more resilient to future climate change and fire regimes	Select novel species or Ash provenances to replace local Alpine Ash. Experimentally sow/plant Alpine Ash provenances which are better adapted to climate change, or sow/plant resprouter eucalypts. See **Box 15**, regarding Greening Australia

[58] Note that 'ecological stocking' is not explicitly defined for Alpine Ash and requires more research on the minimum stocking to maintain Alpine Ash persistence. See Appendix 2 in Bassett *et al.* (2014b) for further discussion on minimum environmental stocking.

[59] Note that this management regime, while explored extensively in scientific literature, has had little application and should only be considered in an adaptive management approach with significant associated research to understand its consequences.

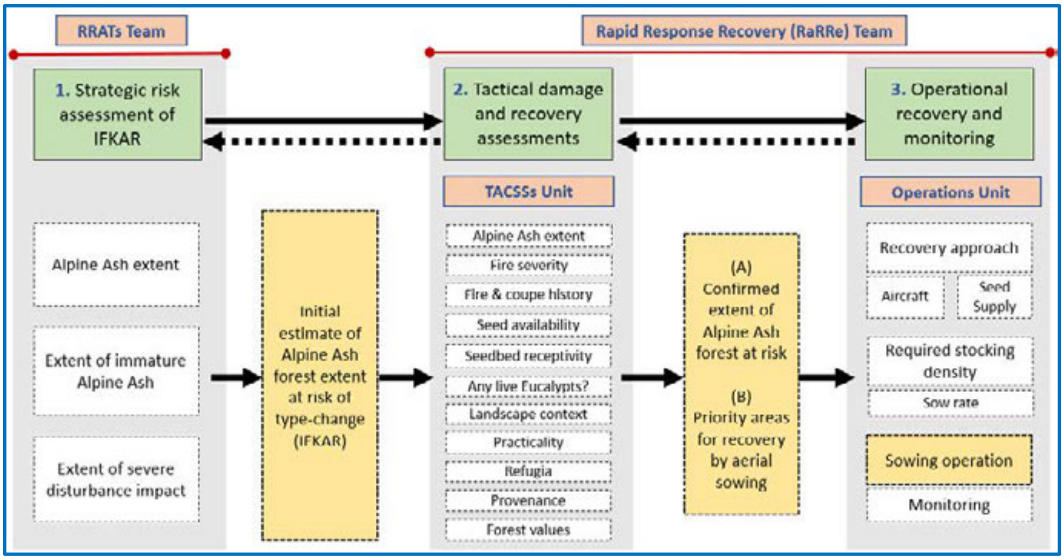

Figure 112. Framework for Ash recovery. This framework outlines the key stages (green boxes), information inputs (white boxes), outputs that form part of assessing the scale and necessity of recovery (yellow boxes), and the four responsible teams/units (orange boxes). Dashed arrows indicate feedback of new information. 'IFKAR' = Immature Fire Killed Ash Regrowth. See text re: team names.

7.4.1 Determining the timing of Alpine Ash recovery

Following a bushfire, the timing of operations is critical. The recovery program needs to take place rapidly, ideally prior to close June in the winter following bushfire (Poynter *et al.* 2009), dictating a window of 4½ months. This window is governed by two factors:

(1) Alpine Ash seed ecology, see Chapter 4

Alpine Ash seed requires the cool and moist conditions associated with winter to break dormancy and germinate in spring (Grose 1960b). Aerial sowing must therefore be undertaken only in late autumn to mid-winter to ensure successful germination, and

(2) The ideal seed bed conditions immediately following a bushfire

Alpine Ash seed requires a loose-surfaced ash-bed without any competing vegetation (Grose 1963). These conditions are present in the months following a severe bushfire, but are lost following the first winter. Recovery depends on the immediate use of this opportunity.

Mechanical treatment such as clearing, ploughing, furrowing or ripping can also create a suitable seed bed (McKimm & Flinn 1979; Lutze & Geary 1998). However, these methods are costly and logistically complex given the extreme topography and remoteness of most Alpine Ash forests, and so are generally not viable. Mechanical site preparation can only be viable following smaller disturbances like windthrow, in addition to use of fire if appropriate.

This rapid timing ensures seed is sown prior to the first snow falls. Procedures and resources must be in place prior to every fire season. Refer to NFSG No. 17 for a discussion on the rapid and extended phases of forest recovery (Poynter *et al.* 2009).

7.4.2 Stage 1. Strategic Risk Assessment of IFKAR

The RRATs team rapidly estimates the broad extent of forest at risk of type-change by utilising three spatial data layers:

(i) The spatial extent of the Alpine Ash forest type

There are a range of existing vegetation or ecosystem spatial datasets maintained by the Victorian Government that can assist building this data layer. Unfortunately, none of the spatial datasets represent the 'perfect' dataset, with each having advantages and shortcomings (**Table 17**). Some are more reliable in certain parts of the forest estate, others contain useful composition and structural information, and some are legacy datasets which are no longer maintained or updated. The suitability of the spatial data will be determined by the region of Alpine Ash forest that is impacted, and which of layers either perform best alone or in conjunction with each other.

(ii) The bushfire extent, with fire-severity mapping to identify severe damage

Fire severity mapping is generally available to the RRATs team rapidly following bushfire, owing to the development of expedient tools which classify satellite imagery (Collins *et al.* 2018). These products produce spatial data which relates fire severity to the scorch intensity of the overstorey – crown burn; crown scorch; moderate crown scorch; light crown scorch; and understorey burn. Some products differ in respective level of leaf scorch in each of these categories (Collins *et al.* 2018; DSE 2009; Gibson *et al.* 2020) but generally, immature Alpine Ash stands impacted by crown burn or crown scorch (the two highest fire severity categories) are likely to die and be at highest risk of type-change.

(iii) Fire history to help inform forest age

Assessment of regeneration capacity by the RRATs team in Stage 1 is confined to use of forest age as a predictor of immaturity and possible type-change. Knowledge of actual seed crops are not considered at this early stage. In State forests, the SFRI spatial dataset (**Table 17**) usually contains information on the regeneration year of forest stands and can be used to map the distribution of immature stands. In areas without SFRI coverage such as National Parks, stand age can be inferred using the most recent severe disturbance data available, such as fire history, and by mapping the intersection of this with the extent of immature Alpine Ash.

<u>RRATs Team Stage 1 output</u>:
A large scale spatial dataset estimating the extent of impacted Ash of all age classes and by all fire severity classes. This includes an estimate of immature fire-killed Ash regrowth (IFKAR) within the bushfire area.

7.4.3 Stage 2a. Tactical Damage and Recovery Assessments

The objective of the TACSSs unit is to provide spatial and technical sowing recommendations to the Operations unit during the rapid response and recovery phase, with sowing shapes prioritised (**Section 7.4.4**) to ensure efficient use of limited seed resources (see Poynter *et al.* 2009).

Table 17. Summary of key spatial datasets which help understand the extent of Alpine Ash forest for land managers in Victoria. A useful hack used by the TACSSs team to assist their detailed species analysis where historic coupes are located, is the harvesting history GIS layer. Accurate species information is usually included in that layer. TACSSs also identify previously unknown distributions of Alpine Ash.

Spatial Dataset	Background	Benefits	Shortcomings	Source	Context for application
State Forests Resource Inventory (SFRI)	Developed as part of the SFRI program; see (Hamilton *et al.* 1999).	Provides both species and composition (proportion of Ash and other eucalypts) and forest condition such as regen year and silvics, although conditional on the version available.	SFRI data is generally not available in National Parks; with some exceptions. SFRI was developed for the State forest estate. Some errors from original mapping, but API can correct these when used.	Victorian Government*	Where fire impacts State forests or areas of National Park only recently converted from State forest (since about early 2000s).
Structural Vegetation (SVEG)	Developed by the Land Conservation Council throughout the 1970/80s. Generally based on height, density and composition of the overstorey canopy.	Cross tenure (State forests, National Parks, Private land) data on forests which can be generally characterised as 'Alpine Ash'.	A legacy dataset which is not maintained or updated. Mapping of vegetation communities is generally coarse and historical. Forest type boundaries are less reliable than SFRI. Does not include any information on species mix or age.	Victorian Government*	High level estimation of Alpine Ash where fire impacts both National Park and State forest estate. Can help fill gaps in SFRI.
Ecological Vegetation Classes (EVC)	EVCs are vegetation classes modelled on floristic, structural and ecological features. Developed as part of old growth mapping in East Gippsland; see (Woodgate *et al.* 1994)	Delineates Montane Wet and Damp Forest, which may be useful for distinguishing between some pure and mixed Alpine Ash stands. Note that other EVCs may contain Alpine Ash in smaller proportions (see **Chapter 2**).	These vegetation classes are modelled and boundaries are not accurate. May overestimate or underestimate Alpine Ash forest extent, depending on area. Coarseness of scale makes it useful only when using as a compliment to SFRI and SVEG.	Victorian Government*	Recommended for estimating impacted Alpine Ash only when no other data available, or as a compliment to other data.
Past TACSSs assessments	Forest recovery data sets since 2013 represent the extent of Alpine Ash inside fire extents. These include areas of previously unknown Alpine Ash in National Parks.	The only current data sets with newly added Ash distribution based on Aerial Photo Interpretation (API). Added knowledge about Ash in National Parks.	Unverified on the ground. Limited in extent, and does not necessarily capture all unknown Ash in the areas of additional mapping. Full extent of Ash in National Parks still not known.	Victorian Government* Forest Solutions (e.g. Bassett et al. 2021)	Access and consider whenever Alpine Ash distribution is required. Could be used to update existing SFRI layers.

*www.data.vic.gov.au

The spatial data sets required to achieve this task can be overlayed in a GIS environment to identify the target space, and include: *(a)* the extent of Alpine Ash within the fire boundary; *(b)* a suite of digital imagery types (see below); *(c)* any past digital imagery from previous fires or other-purpose acquisitions; *(d)* RRATs scorch intensity mapping from the current and previous fires; *(e)* Timber harvesting coupe history pre 2004; and *(f)* past VicForests' (VF) Timber Release Plans (TRP) from 2004, including VicForests harvested coupes regenerated by DEECA post-2023.

The following components make up the set of digital imagery that is required:

(i) *Rapidly acquired, remotely captured, high resolution, multi-spectral imagery.*

Currently captured at 15-20 cm resolution, with developments trending to 5 cm resolution. Colour and infra-red spectrums needed. Formatted in large format mosaics for GIS application.

(ii) *Satellite captured, lower resolution (10 m or less), multi-spectral imagery, such as Sentinel 2.* Used if the above high resolution images are not available in time.

(iii) *Aerially acquired, georeferenced, large format, oblique images - ideally covering the full extent of Alpine Ash within the fire area, and flown at 2-3,000 feet a.g.l.*

Viewed alongside corresponding vertical images to assist interpretation and analysis.

Mapping the extent of Alpine Ash

The same vegetation data sets used by the RRATs team for building an estimate of Alpine Ash extent (**Table 16**) are available to the TACSSs unit. SFRI and SVeg100 are the important data sets. EVC mapping can be used to indicate likely areas of Ash when other data sets are missing. These are intersected with georeferenced imagery mosaics to assist verification of existing mapping and to discover previously unknown distributions, especially in National Parks where SFRI is mostly absent. This newly identified Ash can be accurately mapped down to polygon sizes of 1-3 ha.

New mapping by previous TACSSs units during earlier fires can also be utilised to assist building the currently known Ash extent (**Table 17**). The TACSSs unit therefore creates an updated, new understanding of total Ash distribution within the current fire area. This refined spatial data can be fed back to Stage 1 and used by the State government to update the official Ash distribution layer for future applications.

Utilising the harvest coupe and TRP history data sets is also a useful hack employed by the TACSSs team during Stage 2 analysis to assist verification of forest type in localised areas where other data sets are unclear. The record of forest type and eucalypt species on harvesting coupes are considered accurate given they have been ground-truthed during early coupe reconnaissance prior to harvesting.

Determining a forest's capacity to naturally recover

In silvicultural practice, successful Alpine Ash regeneration requires a source of seed and a receptive seedbed with minimal competition (Grose 1960b; Campbell *et al.* 1984; Florence 1996).

Information such as age class and seed crop status are required to identify a lack of seed supply. Data sets like SFRI, fire history and coupe history can inform forest age, identifying immature forests less than 20 years of age. The annual flower and seed forecast (**Section 4.2**) gives a landscape-level indication of expected seed crop intensity in mature forests by geographic area.

Recapping, that a paucity of seed may be present due to the following two reasons (see **Section 7.2**):

(i) The growth stage of the forest is 'immature' (<20 years of age) and are not considered to carry reliable seed crops (Bassett 2011; Fagg *et al.* 2013; Bassett *et al.* 2015b; Lutze & Bassett 2020), or

(ii) A poor seed crop is present in mature forest at the time of disturbance, meaning insufficient induced seedfall, either due to a series of suboptimal flowering seasons or due to losses of floral components prior to seed set. Strategic Seed Crop Assessments (SSCAs) can be used to confirm seed crop status post-fire (Bassett 2011; DELWP 2020). See **Section 4.2** for predicting seed crops. Examples of previous post-fire SSCAs include Lutze & Terrell (2000), Fagg *et al.* (2013), and Lutze & Bassett (2020). A recent flower and seed crop forecast example is Bassett (2023).

Seedbed receptivity is assessed from aerial imagery for each polygon using the key indicators of fire severity, such as presence of white/orange ash, size of unburnt organic material, extent of blackened ash bed, and scorch intensity on original vegetation if still present, or if this latter is absent. The level of surviving vegetation is relevant, with its spatially consistent presence indicating an unreceptive site; (a) because live vegetation indicates cooler fire with duff litter layers still in place, and (b) because live vegetation or overwood will directly compete with any new germinants (Lutze & Geary 1998; Bassett & White 2001).

Assessing fire damage and coding the capacity of a forest to recover

To determine the level of damage inflicted on Alpine Ash by the fire, and to assess the capacity of the forest to naturally recover, the TACSSs unit undertakes an assessment of scorch intensity (fire severity), stocking status of live Ash, the natural recovery capacity of Ash forests, and seedbed receptivity - which includes level of competition from other live components (**Table 18**).

Appendix 1 contains the detailed assessment criteria used by the TACSSs to undertake tactical damage and recovery assessments during post-fire forest recovery. These assessments are concurrently undertaken for each vegetation polygon of fire impacted Ash across the Alpine Ash extent as each polygon is identified. The order in which these elements are assessed, for each polygon of Ash, is detailed in the TACSSs' Decision Support Systems (DSS) at **Figure 112** (**Section 7.4.4**). A digital code for each assessment category is recorded for every Ash polygon according to **Table 18**. This work produces a digital data set that helps support priorities for sowing (**Section 7.4.4**).

To better interpret impacts of the current bushfire in question, vertical imagery and scorch intensity mapping captured previously during 2003, 2007, 2009, 2013, 2014[60], 2018, 2019 and 2020 can be used to interpret forest condition at earlier stages prior to the current fire. This helps build a time-lapse understanding of multiple, short-interval bushfire impacts, enabling accurate determinations of multiple-burn outcomes, potential now for natural recovery, the need for silvicultural intervention, and for identifying likely forest type-change.

Table 18. Assessment categories and codes (bracketed) for determining and recording the forest recovery status of Ash-type forests following a bushfire. Refer to **Appendix 1** for a more detailed explanation of codes and criteria.

Category	Coded assessment for each Ash polygon
Scorch intensity[61] (SI)	Crown burnt (SI-1), Crown scorched (SI-2), Partial scorch (SI-3), Ground fire only (SI-4), or Unburnt (SI-5)
Live, surviving Ash	Unstocked (U), Partially stocked (P), or Fully stocked (S)
Capacity for natural regeneration	Seed-fall (1), Priority 1 sowing (2), Priority 2 sowing (3), Will not recover (4), has already type-changed (5), or surviving regrowth Ash (6)
Seedbed and competition	Receptive (R) or Unreceptive (U)

TACSSs Unit Stage 2 output

A landscape-level dataset of high resolution, identifying an accurate distribution of immature Ash down to 1-3 ha polygon size[62], using **Table 17** data sets and verifying age from others data sets like coupe history and Aerial Photo Interpretation (API) of multispectral vertical imagery. The spatial data set is analysed concurrently to identify area ‘shapes’ predicted to type-change and those of this set that qualify for restoration.

During Stage 2 analysis, candidate sites for recovery are prioritised during assessment of capacity for natural recovery using **Table 18** elements and the decision support in **Figure 113**. These priorities are submitted as a shape-file recommendation to the Operations unit for considering priorities (**Appendix 2**, example). The next section (**7.4.4**) considers this decision process, as applied by the TACSSs unit, to set priorities against candidate sites for recovery.

7.4.4 Stage 2b. Setting priorities for recovery intervention

Recommended priorities are always made by the TACSSs unit at the time of assessment, in case these are needed later at sowing time. Both seed availability in storage at the time of sowing, and what was naturally available in forest canopies at the time of the fire, is not known for some time after the fire. More seed may be collected during the period from ‘fire contained’ to aerial sowing, and Strategic Seed Crop Assessments take until April or May.

[60] 2014 aerial photography included imagery captured by a local shire for purposes other than bushfire, enabling a review of 2007 Macalister forest recovery at age 8 years following the 2018 fires.

[61] Meaning the severity of scorch inflicted on tree crowns and other forest components.

[62] Considered the minimum management unit area.

Figure 113 provides the Decision Support System (DSS) designed to provide the TACSSs unit with a logical flow of analysis for identifying candidate sites for recovery, polygon by polygon, and for prioritising recovery actions where intervention is required. The flow of analysis directs analysts through a series of questions regarding **Table 18** elements while also considering other aspects and inputs.

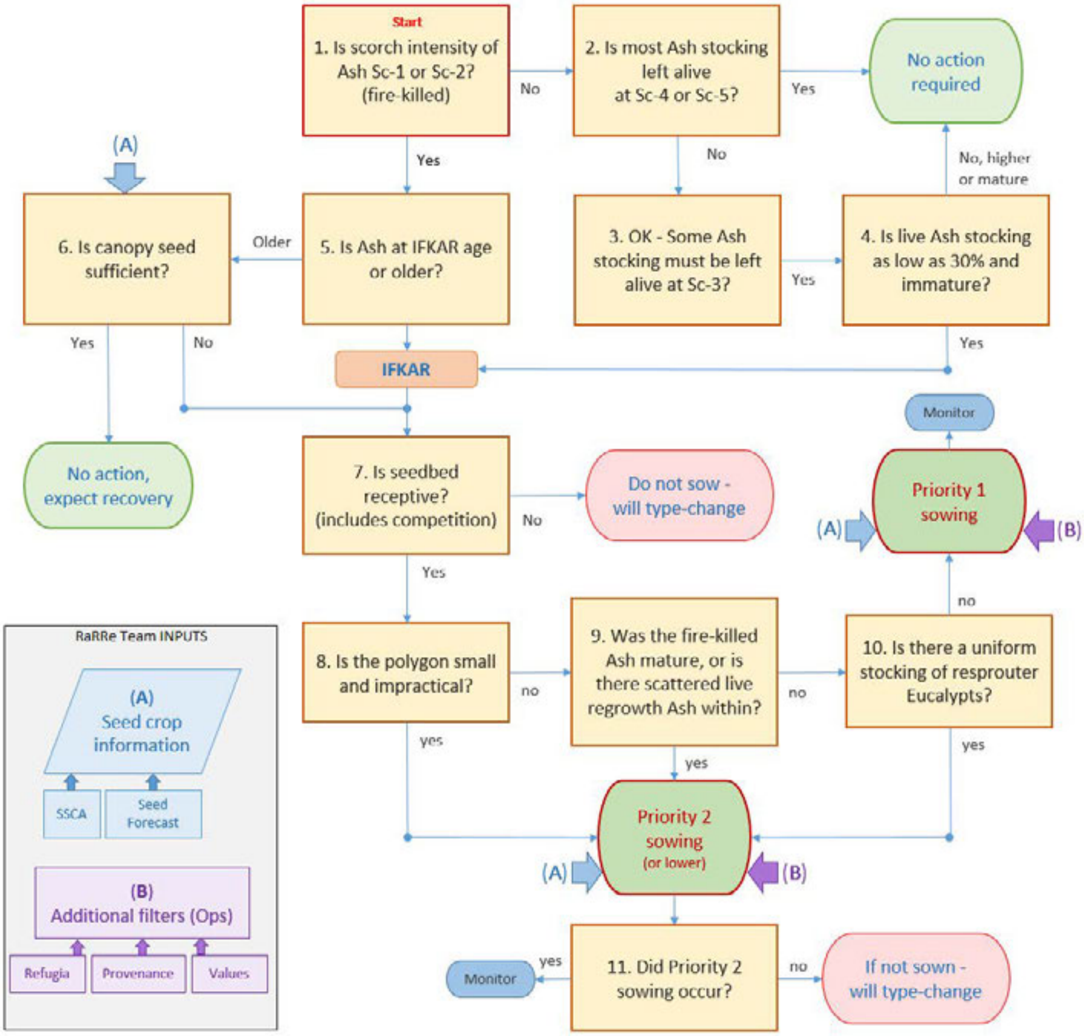

Figure 113. Decision Support System (DSS) for the Tactical Silviculture Specialists (TACSSs) unit to use for identifying candidate sites for recovery and setting recommended sowing priorities. At "RaRRe Team INPUTS", 'SSCA' stands for Strategic Seed Crop Assessment. Note: seed crop information must be considered at points labelled "**A**", and additional filters can be applied to sowing recommendations by the Operations unit at points labelled "**B**". **Table 19** presents three levels of possible priorities.

In a GIS environment, the TACSSs unit considers areas of forest by vegetation polygon – in this case, Alpine Ash. An area identified as being at-risk of type-change is known as 'candidate sites for recovery', and could be formed from multiple polygons, ending up as large as 500 ha. In general, identifying candidate sites and understanding their priority depends on the damage inflicted and the landscape and the *insitu* context of the damaged forest. Because resources are limited and priorities for sowing needed, this usually means that decisions have to be made that will leave some candidate sites unsown. The objective is to minimise the extent-of-impact of untreated sites on broader forest values. **Table 19** provides a summary of common examples of Priority 1 to 3 candidate sites.

Table 19. Guiding examples of three different priority levels for forest recovery intervention. These are also depicted in **Figure 112** as a Decision Support System (DSS) to assist logical work-flow, analysis decisions in real-time, and setting priorities for recovery intervention.

Priority level	Candidate site description (guide only)	Instructions for action
Priority 1 (Pr-1)	• Immature Fire killed Ash Regrowth (IFKAR) • Sc-1 or Sc-2 • Larger polygons >30 ha • No uniform scatter of live Ash • Situated in a widely damaged landscape	Highest priority sowing. Sow first. Consider reduced sow-rates to spread seed further, especially if IFKAR has some on-site seed.
Priority 2 (Pr-2)	• As for Pr-1, but ≤30 ha and >10 ha • Could have a low stocking scatter of live regrowth Ash throughout (Sc-3) • Could have a good stocking of surviving resprouter eucalypts, having been a mixed forest originally. • Could be situated in a lower damaged, live forested landscape • Any Pr-1 sites that have been demoted by other priority filters applied by the Operations unit	Sow only if Pr-1 sites have been sown, AND there is still sufficient seed in store. Again, reduce sow-rates if possible.
Priority 3 (Pr-3)	• As for Pr-1, but ≤10 ha • Fire-killed mature forest without sufficient canopy seed to recover, based on seed forecasting and a Strategic Seed Crop Assessment (SSCA). • Any Pr-1 or Pr-2 sites that have been demoted by other priority filters applied by the Operations unit.	Sow only if Pr-1 and Pr-2 sites have been sown. Likely be a supplementary sowing at minimum rates, because mature forest usually has *some* seed.

7.4.5 Stage 3. Operational Recovery and Monitoring

The objective of the Operations unit is to consider recovery recommendations from the TACSSs unit, finalise priorities for recovery, and expedite recovery actions while being mindful to plan efficient use of limited resources. The following tasks need rapid attention:

(i) Finalise **sowing priorities** in Table 4 and produce a corresponding shapefile of sowing 'shapes' to assist aircraft navigation and aerial seeder application. Consider the additional filters of refugia, special provenances, and forest and biodiversity values (see later in this Section).

(ii) Consider any canopy seed information, such as SSCA data and seed forecast information, to finalise **sowing rates** alongside advice on this matter from silviculture specialists. (Bassett 2011; Bassett & Lutze 2020; Bassett 2023)

(iii) Understand final **stored seed-lot availability** and **provenance information** to assist appropriate **seed allocation** to shapes. If seed is very limited, reduce sow rates to acceptable minimums to ensure at least an environmental stocking (**Table 16**). Note that minimums will usually be dictated by the type of aerial seeder. Sow rates for fixed-wing can be as low as 0.3 kg/ha, and with chopper 0.5 kg/ha. (Wallace 1994; Bassett *et al.* 2015b; Fagg 2001; Bassett *et al.* in prep).

(iv) **Allocate seed-lots** to shapes for aerial sowing, based on established sow-rates, while considering State transfer guidelines (Fagg 2001; Bassett *et al.* in prep).

(v) Arrange an appropriate **aircraft fleet** tailored to the sowing operation at hand. Both fixed-wing and rotary-wing (helicopters) are available.

(vi) **Bag and label** allocated seed, ready for transfer to the aircraft fleet.

(vii) Plan and undertake the **sowing operation** prior to close June, being sure to record flight lines to verify adequate seed coverage (Poynter *et al.* 2009).

The Operations unit need to further consider three particular <u>aspects</u> and three <u>filters</u> in addition to decision points presented in **Figure 113** when selecting candidate sites for forest recovery, forming the following six principals.

1. Considering seed: Artificial and possible natural sources

As for the TACSSs unit, the Operations unit continues considering the availability of artificial and natural sources of seed, right up to the point of sowing. New information may become available after the TACSSs unit makes its recommendations. Artificial sources relevant to the Operations unit include seed stored in DEECA's Strategic Seed Bank and further collection quantities that may be achieved prior to sowing. Previous VicForests' seed stores are now managed by DEECA. Natural sources include known canopy seed storage that has been confirmed by using seed traps to monitor seedfall immediately after the fire and/or using a Strategic Seed Crop Assessment (SSCA) (**Figure 114**; Bassett 2009a; VicForests 2009; Bassett 2011; DELWP 2020). This monitoring and assessment may be recommended by the TACSSs unit, depending on the results of the most recent annual seed forecast. **Table 20** summarises the requirements for assessment, including sampling intensity.

Estimating canopy seed store at the time of the fire is therefore some combination of seed forecasting data, post-fire capsule crop assessments and seed fall monitoring (**Figure 114**), the latter using up to a dozen strategically placed seed traps, and germination of soil-borne seed in soil samples taken soon after the bushfire during SSCA assessments.

The quantity of seed contained in storage determines the extent of the recovery operation and the level of prioritisation required. As a rough guide, each tonne of stored seed equates to approximately 1-2,000 hectares of forest that can be resown, though this depends on seed viability, sowing rate, and the desired stocking density (Fagg 2001; Bassett *et al.* 2014b).

Table 20. Summary of recommended seed crop assessments following a bushfire that has impacted Ash forest. Seed traps can also be used to test seedfall after a fire (**Figure 114**).

Assessment	Seed forecast status	Summary of information required	Operational outcome
Mature SSCA	Very poor seed crop year landscape-wide. Likely one year per decade.	• Canopy estimate and soil-borne seed tests – priority focus on mature forests • Include age classes above 50 years only • When poor seed years occur in mature forest, no seed can be expected in IFKAR; therefore, no IFKAR assessment is required. • High plot intensity	• Confirms any need to sow mature forests • Likely outcome would be to supplementary sow only • Prioritise IFKAR sowing • In mature, prioritise refugia and modelled lower risk sites.
IFKAR SSCA	Intense, uniform seed crop year. Likely 2-3 years per decade	• Switch focus from mature forests to IFKAR and other young forest age classes • Mature forest assumed to naturally recover • IFKAR is priority in age classes <20 years and matching fire/logging histories • Include a secondary priority assessment of age classes 20-30 and 30-50 years. • Low plot intensity	• May indicate some seed crop in IFKAR • If so, reduce sow rates may be justified. • May need to sow older young forests in the 20-50 year age classes
Full SSCA	Good seed crops but may be spatially scattered and variable Likely 6-7 years per decade	• Focus on geo regions that annual forecast indicates are poorest • Canopy estimate across all ages • At least a moderate plot intensity in all age classes – perhaps higher in mature forests • Again, least priority on IFKAR, as this will likely contain no seed	• Similar for Mature SSCA • Sampling design should achieve knowledge of target geo regions. • Will help set targeted sowing priorities.

Figure 114.

(Far left) Carolyn Slijkerman setting up 1 m^2 seed traps to monitor Alpine Ash seed fall in the Kiewa area immediately following the 2006/07 Great Divide bushfire. (Image: DEECA)

(Near left) Cameron Paterson monitoring seed crops on a SSCA plot following the 2009 Black Saturday bushfires.

When canopy seed storage is limited, consideration can be given to the likelihood of which notionally 'immature' Alpine Ash stands may be 'maturing' and therefore have some capacity for seed-based natural regeneration, thus attracting a lower priority. For example, evidence of flowering in relatively young Alpine Ash forests may mean that very light seed crops may be available in 10 – 20 year old stands (Doherty *et al.* 2017a; Gale & Cary 2021; Lutze & Bassett 2020); indeed, during the 2019/20 Alpine Ash recovery program, light seed crops assessed at 51,000 seeds/ha were observed on 17 year old Alpine Ash regeneration (Lutze and Bassett, 2020). This is a very low seed crop – representing between 0.1% to 3% of a mature Alpine Ash seed crop (Lutze and Bassett 2020; O'Dowd and Gill 1984). But if artificial seed reserves are limited, maturing young stands in the 15 – 20 year age cohort may be deprioritised compared to 'more' immature stands. Prioritisation decisions relating to these matters should be supported by targeted seed crop assessments (Bassett 2011; DELWP 2020; Poynter *et al.* 2009) in addition to consultation with research staff and silvicultural specialists before deprioritising Alpine Ash forests in the 15-20 year age class.

2. Considering aircraft for aerial sowing of seed

Figure 115 provides images of various aircraft configurations for aerial sowing, including belly mounted delivery systems with either internal or external seed hoppers.

Figure 115a. The fixed-wing aerial sowing configuration used to sow larger shapes following the 2020 bushfires. Air Tractor **(left)**, showing belly-mounted fertiliser unit with internal hopper, modified for Ash seed delivery **at right** (Pay's Air Service).

Figure 115b. Two rotary-wing aerial sowing configurations used to either sow smaller sowing operations, or the smaller shapes in large sowing operations. **(Left)** under-belly heliseeder spinner system with internal seed hopper (Paton Air Helicopters). **(Right)** An air-blown delivery system with external hoppers (Forest Air Helicopters).

Table 21 summarises the recommended application of aircraft types with respect to project size, size of individual sowing areas, and practicality to sow with respect to physical shape and terrain position of sowing areas - known as 'shapes'.

Sowing operations over 5,000 ha are considered large and challenging, needing a fleet of multiple aircraft with both fixed- and rotary-wing configurations. At the Individual shape level, sowing areas greater than 50 ha are considered large and best sown using a fixed-wing aircraft because of its more rapid coverage of seedbed area.

Because fires are predicted to be large in extent due to climate change impacts, further development of Victoria's fixed-wing seeder-fleet is required so that sowing capacity is better matched to seed store levels and the larger quantities of seed expected to be sown following future bushfires (Ferguson 2011; Bassett *et al.* 2021).

Table 21. Summary of recommended aircraft for aerial sowing Ash seed.

Aircraft type	Current configurations available	Desired situation
Fixed-wing (**Figure 115a**)	Air Tractor. Belly mounted, air delivery system	• Consider for larger projects (say, >1,500 ha) • For sowing shapes >50 ha • Shape sizes up to 500 ha have been sown • Suited to shapes with a clear long-axis • Suited to simpler physical shapes • Suited to more undulating terrain.
Rotary-wing (**Figure 115b**)	Jet-engine craft only Heliseeder spinner or belly mounted air delivery systems.	• Use for all projects with sowing shapes <50 ha. • Could use exclusively for 'small' projects <1,500 ha • Suited to all shapes, but specialised for complex shapes in more difficult/steeper terrain.

3. Considering sowing practicality and managing for realistic outcomes

The distribution of Alpine Ash forest, which can occur in large contiguous stands or in small pockets in the landscape, and the patchiness of disturbances like fire can lead to a wide range of patch sizes and arrangements for forest recovery. Not every patch of forest that is at risk of type-change necessarily requires recovery action. Rather, taking a pragmatic approach to ranking the relative importance of patches is recommended.

Small patches may not be operationally feasible for recovery operations. In these areas it may be preferable to allow natural regenerative processes to occur and to monitor the outcomes. Most ecosystem services, such as habitat provision, may still be provided by the post-fire ecosystem that develops (Seidl *et al.* 2016). Large (> 50 ha) patches should be higher priority targets for recovery because, when extensive and contiguous areas are at risk of type-change, there can be greater consequences for landscape-level ecosystem services like habitat continuity and carbon sequestration. Larger patches will also take longer to naturally recolonise relative to small patches with nearby seed sources. It is also easier to plan and execute recovery operations for large patches. Where Alpine Ash at risk of type change is spread across an extensive area, resowing should be conducted widely across the landscape to avoid clusters of resowing effort, which may remain vulnerable to future fire.

4. Additional filter: 'Landscape refugia' from future climate and fire risks

In recent years, there has been rapid development and improvement of datasets and modelling techniques which estimate the relative vulnerability of different forest types to climate change and associated fire regimes (Nitschke and Hickey 2007; Penman *et al.* 2015). For example, climate change and fire risk modelling can identify Alpine Ash refugia within the landscape which may be less likely to persist in the future (McColl-Gausden *et al.* 2021). This research can therefore indicate to managers which Alpine Ash stands in the landscape, if sown, may be at higher risk of burning again or severely over the long term (~100 years) under a range of climate projections. Bassett & Galey (2019) confirm that previously sown and recovered areas are being burnt again by subsequent short-interval fires, then sown. Alpine Ash forest has been particularly targeted by Parks Victoria and University of Melbourne for this research, with outputs utilised by DEECA following the 2020 bushfires to help prioritise sowing operations (refer to **Box 1 in Section 2.4**).

While these modelling approaches are subject to further refinement and development, and do not necessarily guarantee these stands will not burn again within a short-interval, they do assist managers to sort out sowing priorities during recovery planning. In the absence of this data, managers may also use landscape context and topographic features to approximate which stands may be buffered from or vulnerable to future changes in fire regimes. For example, Alpine Ash stands on the periphery of their distribution, on north/west aspects, close to roads, or surrounded by drier landscapes (i.e. dry eucalypt forests) at lower elevation (McColl-Gausden *et al.* 2021) are more likely to be vulnerable to future fire and their priority for sowing lowered accordingly.

5. Additional filter: Provenance

Seed transfer guidelines currently exist describing where seed can be transferred from (collection source) and to where (sowing area) for the purposes of recovery. These guidelines are concerned with the conservation of genetic resources across the landscape. More information on this can be drawn from (Bassett *et al.* in prep[63]). Depending on the diversity of different provenances in store, transfer guidelines may be relaxed, but with a priority focus on elevation due to possible frost tolerance differences.

In future, 'super seed' provenances with higher resilience to climate change impacts may become known, and use of seed from these provenances to fortify routine seed mixes may become an option (see **Box 15**).

6. Additional filter: Forest and biodiversity values

Biodiversity datasets are available which provide landscape level metrics on the importance of certain areas of forest for conservation values based on a range of forest dependent species (VEAC 2017). Complementing these datasets are finer scale datasets that provide the location of observations of specific species, for example, The Victorian Biodiversity Atlas. In addition, forest zoning spatially maps the special values of certain forest stands (DELWP 2019a). These datasets can be utilised when planning Alpine Ash recovery operations to help prioritise where seed is sown.

[63] Version 2, Native Forest Silviculture Guideline No. 2 *Seed Collection*, due 2024; formerly Wallace (1994)

Box 15: Greening Australia searches for 'Super Seeds'

Current emerging and potential climate change impacts, including the loss of species resilience on sites that could be more susceptible to drought and increasing short-interval bushfires, may be better managed with use of Alpine Ash seed from more resilient provenances, should they exist and be identified. Greening Australia is embarking on a project to examine 'climate adjusted seed provenancing', looking to identify 'super seeds' to produce optimal seed mixes for forest restoration, including recovery after bushfire. Should these provenances be identified, Greening Australia (2022) plans to examine the genome DNA markers that indicate resilient traits, with potentially significant influence on future seed management.

It is worth noting that high-level biodiversity values do not necessarily outweigh local sites of known importance. Modelled biodiversity values represent Statewide, strategic, and long-term important areas to a range of forest dependent species. However, collection of field information should be considered and prioritised where the local importance of certain sites is known. A certain area may not represent the highest strategic biodiversity score, but it may have known field records or landscape importance that could prioritise that patch for resowing. For example an area suitable for sowing may not be mapped as high conservation value, but may be adjacent to a known and current colony of fauna that relies on ash for future persistence.

7.5 Approaches to reforestation of Alpine Ash

Where the window of opportunity afforded by disturbance like bushfire or harvesting has passed, and competing vegetation has established the site, the effectiveness of recovery and routine regeneration approaches greatly diminish and reforestation is required. For example, following the 2006 bushfires and subsequent timber salvage operations of Alpine Ash sites at Connor's Plain, substantial areas of former Alpine Ash forest remained understocked. An extensive program of reforestation was undertaken using mechanical site preparation, herbicide treatment of competing vegetation and planting (Sanders 2010; see also **Box 14**). In this section, we discuss some key considerations when undertaking delayed restoration utilising reforestation approaches.

7.5.1 Undertaking reforestation treatments

Once the restoration of Alpine Ash is delayed, or if it were not possible, Bracken and grassland communities can occupy a site very rapidly following the disturbance event, and any residual seedbed receptivity will rapidly diminish. In some cases, understorey tree species like Acacia may also proliferate from soil-borne seed (**Box 16**). Given these lower productive plant communities store less carbon, possess lower habitat value, and are less aesthetically pleasing than Ash forests, reforestation may be required to meet the forest management objectives of the land manager.

Restoration in such instances require site preparation followed by site establishment using sown Ash seed or planted seedling stock. Site preparation is a particularly important consideration, as this will require the removal of established vegetation to expose the seedbed and minimise competition from pioneer species. Because of resource limitations, assessment of the relative costs and benefits of reforestation should be undertaken prior to operations. A factor for consideration is whether the reforestation work could be delayed for an indefinite period until the degraded site is burned by a bushfire. In such instances, fire may effectively 'prepare' the site and therefore potentially save high costs.

Box 16: Reforestation on Toorongo Plateau

There is significant information available relating to reforestation of Ash forests following restoration programs undertaken on the Toorongo Plateau, north of Noojee (**Figure 116**). McKimm and Flinn (1979) investigated techniques for reforestation in this climatically-harsh region. Here, historical short-interval fires (in 1926 and 1939) eliminated the stands of forest, and cold air drainage further limited natural regeneration. While the original forest composition could only be approximated (Mountain ash, Shining Gum and Myrtle Beech were present as remnants), planting trials showed that Shining Gum and Alpine Ash survived and grew better than Mountain Ash and Blue Gum. Due to the area primarily being grass or low shrub-land, ploughing, furrowing or ripping gave satisfactory site preparation, with high nitrogen fertilisers, such as urea, promoting better early seedling growth and survival. Today, the Toorongo Plateau is well forested, providing a diverse range of ecosystem values.

Figure 116. Reforestation on Toorongo Plateau. **(Clockwise from top left)** Prior to reforestation, with 1970s fenced trial plots in the middle-ground; mound ploughing ready for planting in Spring 1988; clearing, windrowing and burning of Montane Wattle; and Montane Wattle prior to treatment (Images: Owen Salkin).

If reforestation proceeds, the type of site preparation is contingent on the nature of the site and the vegetation occupying it. Ploughing and or mounding have been used successfully in the past on sites with short vegetation types, such as grasses and prostrate shrubs. Where sites have taller or older shrubs – for example, old Silver Wattle or Montane Wattle >50 years – site preparation activities such as pushing and heaping, harvesting of timber[64], or spraying with herbicide may be required, as occurred on Toorongo Plateau (**Box 16**). The remaining woody material is then broadcast burnt, or heaped and burnt, to create both disturbed soil and ash bed seedbeds, after which reforestation by planting or seed dispersal can be undertaken. If the windrows are not to be burned, they should be <6 m wide to allow the site to become fully utilised after tree root systems have penetrated about 3 m from each side of the windrow. In recent years, new techniques of site preparation have been developed to deal with the known impact of snow grass on regenerating Alpine Ash, including the use of excavators to 'lyrebird' cultivated spots for targeted planting (**Box 17**). During the Connors Plains reforestation (**Box 14**), an excavator head-mounted herbicide delivery system was included to spray grasses when cultivating spots.

It is worth noting that in the context of native forests, this type of more intensive site preparation will necessarily have trade-offs. For example, dense stands of wattle may form an important habitat requisite for Leadbeater's Possum (Baker *et al.* 2022), and hence balancing the short- and long-term habitat implications of such restoration approaches can be complex. It is notable though that the life span of species like Silver Wattle are less than Alpine Ash, being nominally 60 years compared to 250 years, and that this will cause mid-term site-degradation issues for forest managers once the Wattle begins to die and fall over.

Following site preparation, planting of seedlings or sowing of seed can be undertaken. Note that the species used are currently eucalypt species native to the site, including Alpine Ash, in accordance with the Codes of Practice (DELWP 2022).

If sufficient seed and seedbed are available, sowing provides a cost-effective method of seedling establishment. Planting may be required on sites where the seedbed is not sufficient. In such cases, site preparation can be restricted to 'rows' where planting will be conducted. Planting requires sufficient planning lead time if seedlings of local provenances are required to be raised in nurseries. Generally, nurseries will require 10 months to raise seedlings of sufficient size and quality for planting out in spring, with NFSG No. 9-v2 providing specifications for seedling quality and guarding from browsers (Bassett *et al.* 2010). Planting allows the stocking and seedling distribution to be accurately controlled. Planted seedlings can form heavily branched regrowth if branching is not controlled by active management or presence of dense understorey vegetation, though the importance of this will depend on the forest management objectives and tenure of the site.

One or more years after planting or sowing, the distribution and stocking of seedlings should be surveyed using the methodologies detailed in NFSG No. 10-v2 (Bassett *et al.* 2014a). If regenerating Ash fails to establish, there are several likely reasons, including

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[64]Silver wattle can produce excellent appearance grade timber for furniture, flooring and other applications. It is lighter than Blackwood, so could be more appealing in modern applications.

poor seedbed conditions, frost, pathogens, browsing, and soil desiccation by drought. Follow-up treatments, including infill planting, may be required to ensure regeneration levels meet planned objectives or prescribed levels. If browsing is a factor, control methods such as fencing, tree guarding, and shooting under permit can be considered.

Box 17: Establishing Alpine Ash in grassy areas during reforestation

Developments from East Gippsland. Contributors: Paul Kneale and Mark Lutze

In some areas Alpine Ash grows with a high cover of native grassy understorey. These areas are the most difficult to re-establish after major disturbances, with the lowest first-attempt success rate (Fagg *et al.* 2008; Bassett *et al.* 2012). Alpine grasses form tussocks and become well established, blanketing the area and supressing Alpine Ash regeneration. Such severe grass competition needs to be controlled for a period of time to allow trees to become established.

Alpine grasses are very hardy as they grow in harsh winter conditions, which can also become very dry and exposed during milder months. A tussock can lie dormant during winter under snow, rapidly sprouting new growth after the snow thaws. Its roots occupying the first few centimetres of soil, allowing it to outcompete other plants like newly planted seedlings and natural germinants.

In the past, use of a dozer blade to peel the grass aside has been used as a form of cultivation. But this method displaces topsoil, usually into windrows, including nutrients, organic matter and microflora. To minimise this loss, Mechanical 'Lyrebirding' was developed. This method is effective where heavy debris does not exist, or has been moved into windrows (**Figure 117**).

Mechanical Lyrebirding uses an excavator beak to create 1-2 m diameter cleared patches (**Figure 117**). These cleared patches, spaced to achieve about 1,100/ha, are then planted with seedlings. The method reduces grass competition immediately around the intended planting site, while maintaining the surrounding grassy vegetation to modify the microclimate, which may reduce exposure to harsh icy winds. In addition, the maintained grassy surrounds provide a diversionary food source for herbivores, which is thought to take pressure off planted trees.

Figure 117. Reforestation at Crawford's Track, Swifts Creek district, showing grassy sites needing reforestation **(left)**. Mechanical Lyrebirding was applied, using an excavator mounted beak. Note the cultivated spots with mounded surrounds **(centre)**, which were later planted **(right)** and showing newly sprouted grass competition clear of seedlings. (Images: Paul Kneale).

7.6 Evaluating and monitoring restoration efforts

7.6.1 Stocking density

The target stocking density influences sowing rate, and is a subject dealt with in a number of existing Silviculture Manuals and Native Forest Silviculture Guidelines, and these should be referred to for further operational guidance (Bassett *et al.* 2014b; Poynter *et al.* 2009). Generally, stocking density should be selected based on the longer-term goals for the landscape impacted (see **Table 16, Section 7.4**) and the scale of the recovery operation. For example, in some landscapes the priority may be to maintain Alpine Ash at very low stocking density in seasons when seed availability is limited; first to enable a the more efficient spread of seed across a larger area when substantial areas of Alpine Ash have been impacted, and secondly to sow at an 'ecological stocking' level designed to maintain ecological function and presence of Alpine Ash. Note that stocking standards need to at least meet EVC minimum benchmarks (see **Table 8, Section 4.5**).

7.6.2 Monitoring regeneration following forest recovery

Table 22 provides a summary of assessment types available to monitor performance.

Table 22. Summary of regeneration performance assessment techniques available following restoration in Alpine Ash forests. See Bassett *et al.* (2014b) for details.

Assessment type	Description	Measurement	Application
Germination plots	2 x 1 m plots, can be multiple	Germination process, germination percent	All restoration types utilising seed distribution.
Established Density Survey (EDS)	25 x 2 m transects, can use multiple	Density and stocking Other site parameters	Broad landscape, such as post-fire recovery. Can adapt to become a cotyledon survey in all restoration types distributing seed.
Triangular Tessellation (TT)	Three plants surrounding plot point with triangle sides measured. Plot point contained in triangle.	Density only	In planted areas, such as for reforestation. Estimates density of planted stock.
Variable Radius Plots (VRP)	Seedling count within variable radius plot	Spatial stocking status at plot point	Reforestation to estimate spatial stocking where TT has been used. Include harvested coupes
Preliminary Seedling Survey (PSS)	Seedling presence in fixed plot	Coupe stocking	Reforestation on harvested coupes
Established Seedling Survey (ESS)	Seedling presence in fixed plot	Coupe stocking	Reforestation on harvested coupes

Some level of monitoring regeneration success following reforestation is required to demonstrate performance and to establish a process of review and improvement. There are established techniques for the monitoring of regeneration success in Bassett *et al.*

(2014b). Some are designed to assess regeneration following timber harvesting and aerial sowing, and others following bushfires or planting operations. Some modifications may be required to meet the necessary assessment objectives of a particular project.

Attempts to monitor the results of forest recovery efforts at a landscape scale first occurred following the 2013 Harrietville-Alpine bushfires. At this time, Bassett *et al.* (2015) utilised a stratified sample of germination plots to record the initial germination event in sown and unsown areas, then later utilised an Established Density Survey (EDS) to estimate early density and stocking (**Figure 118**).

Figure 118. Monitoring post fire recovery following the 2013 Harrietville-Alpine bushfire. **(Left)** Cam Paterson establishes a 2x1 m Alpine Ash germination plot with individual germinants tagged using pink skewers **(inset),** and **(right)** Gary Hendy counts germinants in each 1 m^2 plot along a 25 m EDS transect. Germination plots have a 6-18 month life, while EDS plots are usually single use.

EDS assessments were also undertaken within the first 12 months following the 2020 Black Summer fires, in Alpine Ash stands which had been sowed during recovery operations. The aim of these were to provide rapid characterisation of the early establishment trends (Slijkerman *et al.* 2024). Site data recorded at each transect included: treatment, slope, aspect, elevation, estimated percentage of bare ground along transect, presence of ash seed bearing trees and other overstorey present; coarse woody debris; and types of colonising species. These surveys were rapidly employed, and so transects were not marked in the field but this could be considered if repeat measures are required in future.

Such surveys provide a rapid and early forecast of recovery success. However forest managers should consider whether later and more comprehensive surveys are warranted to better assess recovery performance over a longer time-period post-fire. However, such on-ground monitoring approaches are not void of risk, given the overhead dangers typical of multi-burned, fire-killed Alpine Ash trees, such as falling limbs. If such risks are unacceptable, remote sensing approaches may be required. However, it is not possible for these to register early seedling establishment. For example, Aerial Photographic Interpretation (API) may be the best option from both a safety and cost perspective, but can only be undertaken at least six years post sowing to allow for sufficient development of seedlings in relation to other vegetation to provide a clear signature (Mick Hansby, *pers. comm.*).

7.6.3 Monitoring regeneration following reforestation

Depending on the source of regeneration during reforestation, all of the assessment techniques listed in **Table 22** can be utilised. However, planting nursery seedlings is usually a large component of reforestation because of the higher probability of achieving established plants sooner (Bassett *et al.* 2010; **Figure 119**).

Planting density should always be set to at least achieve EVC benchmark densities, and the technique to measure this performance is Triangular Tessellation (TT) - but note that this technique estimates a median density for the whole block of area in question and says little about spatial stocking at any point in the block. If spatial stocking requirements also form the operation's regeneration targets, to identify any discrete understocked areas, then Variable Radius plots can be used alongside TT to demonstrate stocking at plot points where density according to TT falls below target benchmarks. See Bassett & Whiteman (2012)[65] for an applied example of these techniques.

Figure 119. An Alpine Ash 'gritty' seedling, with WR-1 wallaby repellent applied during nursery production, planted into cultivated soil on Connors Plains, 2010.

To gain an improved understanding of regeneration outcomes, the sampling design for plot/transect placement is important, and certain variables can be accounted for through stratified sampling (Husch *et al.* 1982). For example, monitoring of the Connors Plains reforestation (see **Box 14**) stratified the treated areas by soil and understorey vegetation types, enabling an analysis of impact of these variables on regeneration outcomes; see **Section 4.4.1** for an applied example of this.

[65] Available from HVP Plantations, DEECA's Strzelecki Cores & Links team, or Forest Solutions.

Post-script image

Image by Caitlin Cruikshank: Wheelers Creek in Corryong's high-country, south of Mt. Pinnabar following the 2003 bushfires, NE Victoria. Natural regeneration was widespread after this fire, but Corryong's forests were intensely burnt again by the 2020 bushfires (see **Figure 36, page 40**), with many areas unable to naturally regenerate and therefore requiring intervention to recover.

This is a current, key issue and risk for Ash forests in Victoria, requiring an ongoing capacity to respond if we are to maintain these iconic tall forests for future generations. Professor Rod Keenan captures the essence of this message in his **Foreword** to this manual.

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Appendix 1 – assessment criteria

Assessment criteria and stratification used by the Tactical Silviculture Specialists (TACSSs) when undertaking tactical damage and recovery assessments during post-fire forest recovery.

1. Presence of live, surviving Ash – regrowth or mature.

(U) Unstocked:	No live Ash present on the site (< EVC benchmarks).
(PS) Partially stocked:	Patchy Ash, sufficient to at least meet EVC benchmarks for Ash regeneration (predicted 200 stems/ha minimum at age 2-5 yrs, 100 stems/ha at age 10 years).
(S) Fully stocked:	Dense Ash considered to fully occupy the site in terms of a site's ecological productive capacity.

2. Seedbed receptivity and competition

(R) Receptive:	Area is receptive according to key indicators, such as presence of white/orange ash, size of unburnt organic material, extent of blackened ash, and scorch intensity on surrounding vegetation (level 1 or 2). Limited competition. Sowing of seed can occur.
(U) Unreceptive:	No receptive seedbed and/or severe competition. Do not sow.

3. Seed source

(1) Seedfall:	Expected to self-regenerate, due to the presence of at least 20, well distributed, mature, live trees/ha at the time of the fire. Seed is predicted, or known, to be present. Seedbed receptive.
(2) Priority 1 Sow:	No overwood seed source at the time of the fire. Receptive.
(3) Priority 2 Sow:	Some canopy present but predicted to hold insufficient seed at the time of the fire. Some seed may be present. Receptive.
(4) Expected type-change:	No on-site seed, no receptive seedbed, no option for recovery. Type-change, or at least a State-change, is therefore expected.
(5) Already type-changed	Damaged, with type-change already occurring following an earlier bushfire, with no immediate option for recovery.

4. Scorch intensity ('severity' is likely a better term – needs review. This also indicates future seed source)

(SI-1 or SI-2) No or poor survival:	Crown burnt (1) or scorched (2). Survival not expected. No/little future overhead seed source expected in the next 20 years.
(SI-3) Some live trees have survived:	Mosaic of crown scorch/burnt. At least 20 mature stems/ha surviving that could hold a future seed crop after 10 years.
(SI-4) Full live canopy:	Ground fire only. Green canopy. Seed-crops return after 5 years.
(SI-5) Unburnt:	No fire. Green canopy. Full reproductive capacity retained.

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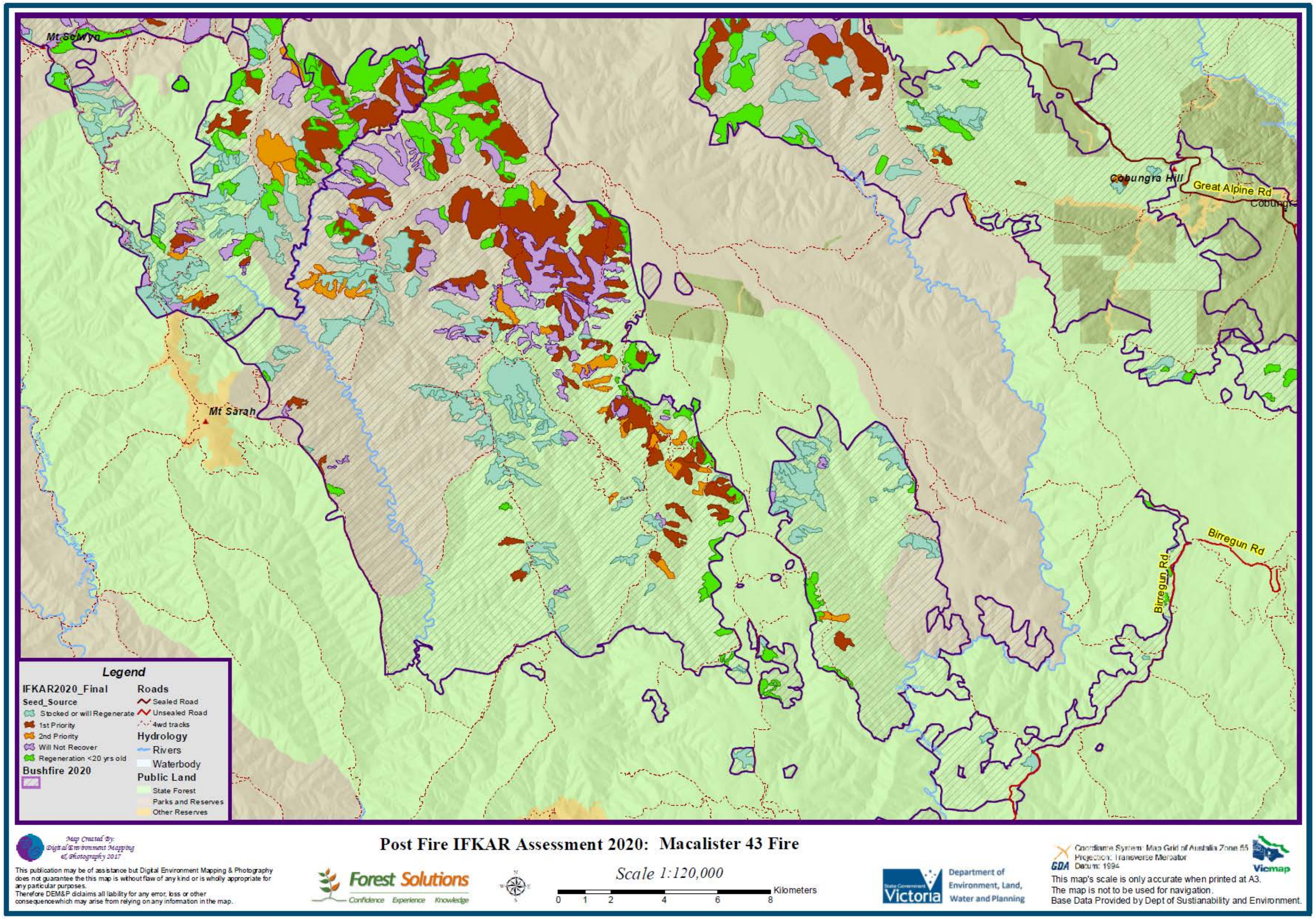
Appendix 2 – sowing priority recommendations

Spatial layer example produced by the Tactical Silviculture Specialists (TACSSs) for the Operations Unit, showing some of the initial sowing priorities following the 2020 Black Summer bushfires. Map produced by Brenda Gailey based on post-fire assessment data collected by Forest Solutions (from Bassett *et al.* 2021).



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Glossary

Active management	The ability to adapt and respond. Expected to include active steps to reduce threats to forests, prepare forests for future threats, maintain the capacity of forests to recover after disturbances, and restore forests that have been degraded.
Age classes	Areas or stands of forest trees originating in a defined year or period of years.
Anthesis	The entire process of 'flowering', beginning with the tear and separation of the operculum rim from the floral tube – prior to the appearance of any stamens.
Apiary	The keeping of European Bees for honey production and pollination services. Victoria's native forests are critical to the apiary industry for feeding and maintaining bee colonies. Alpine Ash can be an important species to apiarists.
Arboreal mammals	Species of fauna living in native forest trees. In Ash forests they are often active after dark.
Backlog regeneration	Coupes harvested for timber in the past but were either not regenerated at the time or, if regenerated, not been surveyed to demonstrate regeneration performance against a Standard.
Basal area	The sum of the cross-sectional areas measured at breast height of the trees in a given stand. Usually expressed as square metres per hectare (m^2/ha).
Biodiversity (biological diversity)	The variety of all life forms; the plants, animals and micro-organisms, their genes and the ecosystems they inhabit.
Biomass	The total mass of all living matter in a defined area.
Bole	The trunk or main stem of a tree.
Breast height re tree diameter	1.3 m above ground level – the point above ground level at which to measure tree diameter or girth.
Clear-felling	A past silvicultural system in which most live trees, not required for environmental purposes, were harvested in one operation.
Code of Practice for Timber Production	Set of principles, procedures, guidelines and standards that specify minimum acceptable environmental practices in harvesting and associated forest management operations.
Co-dominant	Tree with a crown at the general level of the canopy; has medium-sized crown.
Coupe	A temporary planning unit of forest used in the past to identify the area designated for timber harvesting and for regeneration activities. Can also delineate an area for seed-collection by climbing.
Crown	The main canopy of a tree, including main branches and leaves.

Crown, primary	The main, original framework of branches, twigs and leaves that has not been subject to damage.
Crown, secondary	The framework of branches, twigs and leaves that has replaced the (damaged) primary crown. See also 'epicormic'.
Damage	Any injury caused to trees and other forest plants caused by harvesting activities, fire, wind, insect attack or other natural or human induced causes.
Damping-off	Death of small seedlings due to attack by fungi in moist conditions.
DBHOB	The diameter of the main stem of a tree measured at breast height (1.3 m) and over the bark.
DEECA	Department of Energy, Environment and Climate Action
DELWP	DEECA's previous iteration: the Department of Environment, Land, Water and Planning
DEDJTR	Department of Economic Development, Jobs, Transport and Resources (also abbreviated ECODEV)
Decay	The decomposition of wood by fungi.
Defoliation	Temporary or permanent loss of leaves. May be caused by fire, insects, drought or herbicides.
Diameter	The width measurement of trees or logs, usually made at breast height (1.3 m above upper ground level).
Dieback	Death of branches or tips of a tree, associated with disease, insect attack or fire.
Dominant (tree)	A tree with a crown extending above the general level of the canopy, larger than the average tree in the stand, which has a well-developed crown.
Dormancy, primary	A 'specialised survival mechanism' for Alpine Ash given it inhabits the sub-alpine zone. Stops germination in autumn and carries it over winter for a spring germination following cold stratification which break dormancy.
Dormancy, secondary	An induced second-stage dormancy following the breaking of primary dormancy, usually triggered by rapid over-heating.
Duplex	Type of soil profile with distinct A and B horizons.
Environment Conservation Council (ECC)	A body that advised the Victorian Government on the use of public land. It investigates issues on designated areas, taking account of resource use, social needs and environmental issues.
Ecological Vegetation Class (EVC)	The components of a vegetation classification system. They are groupings of vegetation communities based on floristic, structural and ecological features.
Ecosystem	All the organisms (including plants and animals) in a particular area together with the physical environment with which they interact.

Ectomycorrhizae | A non-pathogenic association of a fungus with the roots of a tree, in which the fungus forms a sheath around a fine root and enhances nutrient uptake.

Epicormic shoot/growth (epicormics) | Shoot arising from a dormant bud in the stem or branch of a woody plant, often following defoliation by fire or insects. Contributes to a secondary crown. Alpine Ash does not generally produce epicormics.

Even-aged forest/stand | Forest predominantly of the one age. Usually originating as a result of an intense burn or intensive timber harvesting activity.

Fauna | A general term for animals including reptiles, birds, marsupials and fish.

Felling | Manual or mechanical pushing over or cutting down of standing trees.

Felling cycles | The time between successive (usually selection) harvesting events in a particular area. Referred to also as 'rotation'.

Flora | A general term for plants of a particular area or time.

Forest composition | The proportional make up of different species of each botanical lifeform in a forest. Also referred to as 'species composition'.

Forest function | Identifying the functional components of forest ecosystems, such as nutrient cycling, species and lifeform interactions, hydrology, soil processes, and plant physiology for example.

Forest structure | The architecture of a forest, describing tree density, species assemblages, canopy characteristics, site occupancy, gap dynamics, and basal area and size-class distributions.

Forest Management Area (FMA) | A territorial unit for planning and management of State forests in Victoria. Currently Victoria is divided into 15 FMAs as defined in the Forests Act 1958.

Forest Management Plan(FMP) | A plan dealing with strategic and operational issues of forest management prepared for a specific region and integrating environmental and commercial objectives.

Forest Management Zone (FMZ) | Delineated forest area of similar attributes to which particular Departmental strategies and specific prescriptions may apply. There are three types of zones: the Special Protection Zone, Special Management Zone and General Management Zone.

Forest type | Classification of forests according to;

(a) their life form and height of the tallest stratum, and the projected foliage cover of the tallest stratum, or

(b) their main component species +/- elevation.

Forests Commission | Agency of the Victorian Government responsible for management of State forests in the period 1919-1984.

Frost heave | The lifting of soil as a result of ice formation and expansion in frozen soil. In the process, small seedlings may be pushed out of the soil and thereby killed.

Frost kill | Death of plant tissue or a whole seedling caused by low temperatures.

Genetics	The science of heredity.
Germinative energy	The rate at which a seed lot germinates once imbibed. Also known as 'seed vitality'. Can be increased by stratification.
Growth stages	A system used to describe the life cycle of trees based mainly on crown form – the main ones being seedling, sapling, pole, spar, mature and senescent.
Habitat trees	A tree identified and protected from harvesting to provide habitat or future habitat for wildlife.
Harvesting	The felling of trees; cutting, snigging, preparing, sorting, loading or carting of forest produce from trees which have been felled or which are fallen.
Height	The height above upper ground level to the top of a tree crown.
High elevation	Refers to Victoria's sub-alpine region above 900 metres, where Alpine Ash occurs. The area is subject to harsh conditions such as high winds, frost and snow in winter.
Hollow	An opening in the trunk or branches of a tree often formed after a branch dies and falls off. These can provide fauna habitat.
Landscape refugia	Modelled spatial analysis: Forest patches predicted to more likely persist in the face of climate change and increasing bushfires, given their position in the landscape may provide protection and reduce the likelihood of bushfire at the forest patch's location.
IFKAR	Immature Fire Killed Ash Regrowth – Regrowth Ash below reproductive age, killed by fire and likely unable to naturally regenerate – requires assessment to determine recovery action.
Increment	The increase in volume, diameter, height or other measure of individual trees or stands during a given period.
Inflorescence buds	An early stage of eucalypt flowering in which bud clusters are enclosed within a bract.
Litter fall	Organic material (mainly leaves, twigs and bark) that falls to the forest floor.
Mature forest	A description of a forest stand and/or individual trees where the tree crowns are well foliated and rounded. The height and crown development of the trees has effectively ceased (compared with regrowth) but decline of the crown has not yet significantly begun (as in the senescent or over-mature growth stage).
Mean Annual Increment (MAI)	The total wood increment up to a given age divided by that age, related in m^3/ha.
Mixed species forest	Forest which has two or more eucalypt species commonly found within the canopy. Generally consisting of Peppermint, Messmate or Gum-bark species. Does not include Ash, Red Gum or Box-Ironbark forests, even though the latter has multiple spp.
Mixed-age stand	A forest stand where trees of at least two ages are present.

Nutrient capital The total amount of various elements needed for plant growth held in the part of the soil profile that is accessed by root systems.

Obligate seeder A fire-sensitive species that almost exclusively relies on seed to naturally recover when mature individuals are killed by fire.

Old growth forest Forest which contains significant amounts of its oldest growth stage — usually senescent trees — in the upper stratum and has survived past disturbances – the impacts of which are now negligible.

Operations Unit Post-fire forest recovery The operations team lead by the State to receive, evaluate and review recommendations from the TACSSs Unit relating to damage and recovery of forests following a bushfire, then to undertake forest recovery actions, such as aerial sowing.

Operculum The cap on the top of an unopened eucalypt flower bud.

Over-mature A growth stage of a forest stand or individual tree that is characterised by a declining crown leaf area and irregular crown shape due to a loss of branches and epicormic growth.

Overwood Mature trees that are taller than trees at a lower level. Can refer to seed trees, habitat trees etc, left standing after harvesting.

Parks Victoria (PV) The Victorian Government agency responsible for managing and protecting all National Parks and other conservation reserves.

Pathogen A disease-producing organism, such as a fungus or a virus.

Pedicellate In this case refers to any floral bud with a pedicel – or stem on which the bud is carried. The opposite is ‘sessile’, referring to a species with buds that have no stem.

Pollination The transfer of pollen from an anther to a stigma in a flower or between flowers of the same tree or neighbouring trees.

Population collapse Usually only localised, this refers to a dramatic loss of Ash species from a local area due to severe damage by bushfire, with the Ash unable to naturally recover – usually due to a lack of canopy seed. See also ‘type change’.

Protracted recruitment Unique to Alpine Ash: viable seed still available in soil for germination into the second spring. Never a large proportion, but nonetheless this mechanism can assist overall recruitment.

Provenance The original geographic source of seed or other genetic material.

Psyllid A type of sap-sucking insect which lives under a protective covering called a lerp. Severe infestation causes extensive foliage damage.

RaRRe team Post-fire forest recovery Rapid Response Recovery team. Made up of the TACSSs Unit and the Operations Unit – responding rapidly to recover forests at-risk following bushfires. The RaRRe team takes over from the RRATs team to undertake more detailed assessments and operations

Regeneration *n*. The young regrowth of trees and other vegetation following disturbance of the forest such as timber harvesting or fire.

v. Renewing the forest by natural means or artificial actions.

Reforestation	The re-establishment of a stand of trees by planting or sowing (with species native to the locality) on previously cleared or poorly forested land.
Regrowth crown	Young trees with narrow, conical crowns with relatively high individual crown densities.
Remedial regeneration	Backlog regeneration or second attempt regeneration
Ripping	Breaking up compacted soil by pulling a ripping-tyne behind a tractor.
RRATs team Post-fire strategy	Rapid Risk Assessment Teams – initial deployment of post-fire damage assessment personnel to quickly evaluate damage to forest and community values to inform post-fire strategy.
Root grafting (fusion)	The joining of roots so that water and nutrients can move from one tree to the other.
Rotation	The planned number of years between the regeneration of a forest stand and its next harvest.
Salvage harvesting	Harvesting of forest produce to recover a resource that would otherwise be lost as a result of damage by fire, pests or disease.
Sawlog	A tree log considered suitable in size and quality for producing sawn timber.
Seedbed	The soil onto which seeds are sown or fall, and germinate in.
Seed dormancy	The condition of seeds in which they will not germinate even in apparently favourable conditions. Dormancy can be broken by a variety of treatments, such as moist cold, scarification or heat.
Seed crop density	A measure of the potential quantity of seed (via capsules) held in a single branch, tree or a stand.
Seed longevity	The length of time that a stored seed-lot retains a reasonable level of viability and other measures of quality.
Seed tree	A tree left standing following harvesting to naturally regenerate the site by seed released from the crown.
Seed viability	The number of seeds that will germinate per unit weight of seed. Usually denoted as No./kg.
Seedling percent	The percentage of seeds sown which germinate and become established seedlings at a given period (usually 12 months) after sowing/seedfall.
Selection system	An uneven-aged silvicultural system involving the felling of selected mature trees at intervals over the rotation. Individual trees = single tree selection. Small patches of trees = group or gap selection.
Sequestration	The process of up-taking, capturing and storing atmospheric carbon by trees and lower lifeforms in forests. This is an important value of Ash forests in Victoria.

Short-interval bushfires	Two or more overlapping bushfires separated by less time than the reproductive age of Alpine Ash. Immature stands of Ash are therefore at risk of local population collapse, given their lack of seed.
Silviculture	The science and practice of establishing tree species, while managing species composition and stand structure to achieve specified forest management objectives.
Silvicultural system	A system of active management describing the techniques used to manage tree establishment and the tending of a forest through its entire life cycle.
Site preparation	Preparation of the ground to provide conditions suitable for regeneration by sowing seed or by planting seedlings.
Site quality	The potential of the site to grow trees/timber. A function of soil quality, rainfall and aspect. Often measured as the height of a stand of trees at a given age.
Slash	Tree and other plant debris left on the ground as a result of forest practices, e.g. past timber harvesting, pruning, road construction, etc. Slash includes material such as leaves, twigs, branches, bark, shrubs and solid wood.
Sowing rate	The rate at which seed is sown, usually in terms of either number of seeds per hectare or weight of seed per hectare.
Stand	A group of trees in a forest that can be distinguished from other groups on the basis of uniformity of age, species composition or condition. Usually at least one hectare in size.
State forest	A form of public land tenure in Victoria; managed for biodiversity, cultural heritage, forest products (including wood), catchment protection, recreation, research and education.
Stocking	The ‘density’ of any given forest stand, which can be expressed as: the number of trees per hectare, or the basal area per hectare, or the percentage of survey plots which contain acceptable stems according to a Regeneration Standard.
Stratification	The treatment of seeds by cold and moist conditions for a period of time in order to break dormancy.
Suppressed (tree)	A tree with a crown entirely below the general level of the stronger canopy so to be dominated.
Synchrony	The level to which peak flowering intensity is matched between neighbouring trees (site level) or forest stands (landscape level).
TACSSs Unit Post-fire forest recovery	Tactical Silviculture Specialists – a rapid response unit deployed to identify and help recover IFKAR (damaged) forests following a bushfire in Ash-type forests.
Taproot	The main root growing downwards into the soil, providing stability and giving off lateral roots.
Thinning	The removal of part of a stand, with the aim of increasing the growth rate and/or health of the retained trees.

Timber A general term used to describe

(a) standing trees or felled logs before their processing into forest produce, and

(b) natural or sawn wood in a form suitable for building and other purposes.

Timber harvesting The snigging, preparing, sorting, loading or carting of trees or parts of trees which have been felled or which are fallen in order to produce sawn timber products. Industrial-scale timber harvesting is no longer practiced in Victoria's native forests.

Type-change Change from a forest to non-forest state, usually because of repeat, short-interval bushfires that return at frequencies shorter than the age of reproductive maturity, killing young Ash forest before they can produce sufficient seed to naturally recover. See also 'obligate seeder'.

Could also refer to a dramatic reduction in Ash density or loss of Ash species with other eucalypts remaining. See also 'population collapse'.

Umbellate buds Eucalypt flower buds which occur in an umbel or cluster.

Understorey The layer of vegetation that grows below the canopy formed by the tallest trees in a forest.

Water catchment Defined management units of forests set aside in Victoria for the production and storage of clean water for human communities.

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