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Control of Pine wildings in remnant vegetation: Aspects of management in the Green Triangle Region

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1 INTRODUCTION

There was a little girl
Who had a little curl
Right down the middle of her forehead.
And when she was good she was very, very good,
And when she was bad she was horrid.

Radiata pines (*Pinus radiata*) were introduced into South Australia and Victorian in latter part of the 1800s. The second half of the 1900s saw large-scale plantation development. Breeding for faster growth and greater volume also occurred in this period. In temperate areas with moderate to high rainfall pines grow rapidly, producing valuable timber and wood chips for the Australian and export markets. At the same time, seed from plantations has been the main source of pine wildlings, self-sown trees that establish within plantations or on nearby land. These are a problem for plantations and even more for adjacent native vegetation.

In this report our interest is with control of pine wildlings within native vegetation, particularly in the Green Triangle region: south eastern South Australia and south western Victoria (Figure 1). Table 1 shows the distribution of *P. radiata* plantations nationally, it indicates that the Green Triangle contains approximately 22% of Australia's Pine plantation area. This makes it the second most significant softwood plantation area in Australia.

Table 2: Area of *P. radiata* plantations in the Green Triangle to 2005

Table 1 Distribution of *P. radiata* plantations in 2005 (hectares)

Region	Area of plantation (Hectares)	Per cent of total
Southern WA	59,963	8.10
Mt Lofty Ranges and Kangaroo Is	18,747	2.53
Green Triangle (Victoria and South Australia	**166,185**	**22.44**
Northern Tablelands NSW	15,182	2.05
North Coast NSW	1,447	0.20
Central Tablelands NSW	79,241	10.70
Southern Tablelands NSW	21,788	2.94
Murray Valley	175,354	23.68
Central Victoria	30,747	4.15
Central Gippsland	58,337	7.88
East Gippsland/Bombala	41,956	5.67
Tasmania	71,600	9.67
Total	**740,547**	

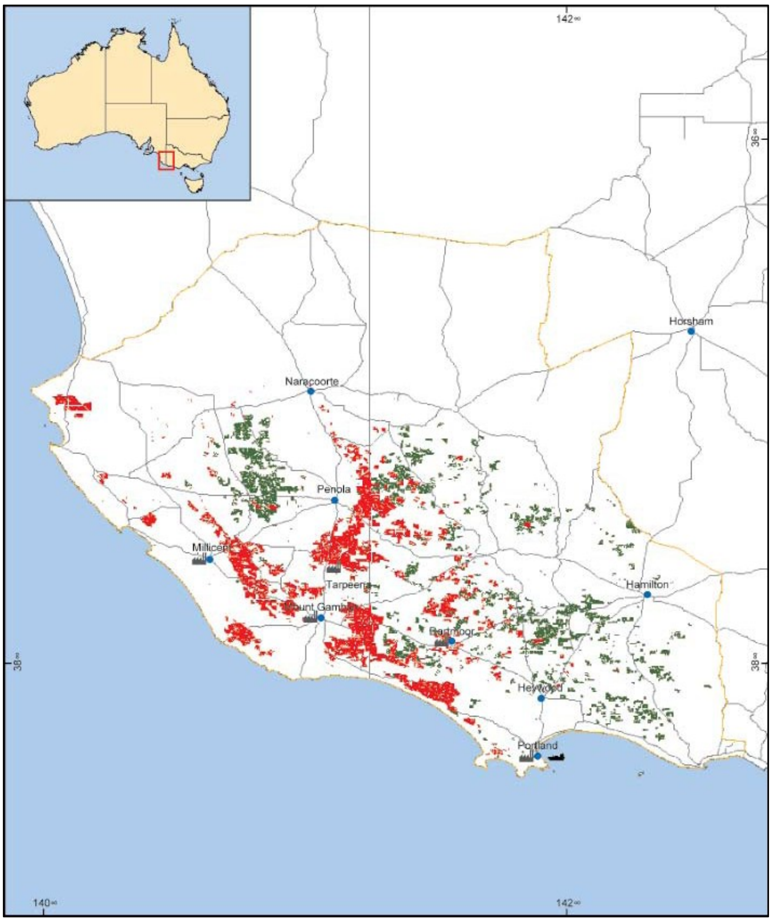
Adapted from Parsons *et al* (2006)

In 2005 plantations supplied a little over half the logs to Australia's forestry and timber industries, which had a gross annual turnover of around $18 billion (Parsons *et al* 2006). At the same time plantations are a source of substantial invasion and modification of native vegetation. Better information may be a step towards effective management of this threat while retaining the benefits of pine production.

Figure 1 The Green Triangle Region

Softwood plantations shown in red, hardwoods in green.

Source: Parsons *et al* (2006)



2 ECOLOGY OF PINE INVASION

P. radiata has been identified as highly invasive in temperate Australia with average rainfall above 600 mm. (Williams and Wardle 2004). Williams and Wardle define *Invasive Species* as those that produce off-spring, often in very large numbers, at considerable distance from the parent plant, and thus have potential to spread over very large areas (Williams and Wardle 2007 a).

Features that make for an ideal plantation plant also allow them to invade and compete with native vegetation: easy propagation, rapid growth under a wide range of conditions, ability to establish on disturbed land and out-compete native plants, tolerance of both shade and exposed conditions, resistance to pests and diseases (Geldenhuys 2004, Richardson 1998). These plants also have obvious benefits that have led to their being nurtured and spread through vigorous human effort, thus increasing their opportunities to invade new territory. Radiata pine displays all these attributes, which make it both an ideal plantation species and capable of being a very effective invader (Higgins & Richardson 1998).

2.1 Sources of information

There has been extensive research into the consequences and control of pine wildlings overseas, particularly in South Africa and New Zealand. Published information on impacts of pine invasion of eucalypt forests and woodlands is more scant. Information on the ecology of pine invasion gives some direction to managing the invasion. Australian studies of *P. radiata* invasion have been undertaken in the ACT and NSW. These include Baker *et al* (2007), Burdon and Chilvers(1997), Cheal (1994), Dawson *et al (*1979), Lindenmayer and McCarthy (2001). Lindenmayer (2002), Richardson *et al* (1994) and Williams and Wardle (2004, 2007 a)

Several have shown that pine plantations are much less useful than native forests as wildlife habits and pine litter greatly alters decomposer organisms, thus changing soil conditions (Richardson *et al* 1994; Parsons *et al* 2006). It is reasonable to expect dense stands of pine wildling growing within native vegetation to be reasonably similar.

2.2 Factors influencing pine invasion

Factors that influence the success of pines as invaders of native vegetation include:

- Life history traits of pines; their ecological or 'vital' attributes).
- Extent of pine plantings and resultant seed load.
- Disturbance of neighbouring native vegetation.
- Density and vigour of native vegetation – i.e. how effectively this vegetation competes for light and other resources.

2.2.1 Life history traits of *P. radiata*

Noble and Slatyer established a process-based approach to understanding the development of vegetation communities (Noble and Slatyer 1980, 1981). This has been accepted widely since they first described the 'Vital Attributes' that determine the process of plant succession after fire (ForestrySA, 2006). Their model established the potential for pines to become a permanent feature of native forests, once they have invaded.

a) Propagules and how they spread – the source of new plants

Pines establish from seed, which is produced in abundance by mature trees. They cannot establish from dormant buds. Seed-bearing cones are produced first on trees 5-10 years old; peek production follows between 10 and 20 years (Richardson 1998, Williams and Wardle 2004, 2007 a). This short time to maturity and large seed production gives pines a competitive advantage over slower-maturing native trees.

Seed are mainly released in hot, dry weather or after fire. The winged seeds are well adapted for wind dispersal, which is the main way that they are spread (Williams and Wardle 2004, 2007 a, b). Wind can carry seed up to 4 km although most falls within 1,000 m of the source.

Birds, particularly Yellow-tailed Cockatoos, can also spread a small amount of seed much further, leading to a few outlier pines (Lindenmayer and McCarthy 2001, Williams and Wardle 2004, 2007 a). These can then become a new seed source and considerably increase the spread of pine wildlings. These outliers need to be identified and targeted for control to minimise development of new fronts of infestation.

b) Establishment – producing new plants

Pine seed can germinate and seedlings establish and grow in both full sunlight and the moderate shade to be found within most eucalypt forests and woodlands, and native shrublands (Burdon and Chilvers 1997, Williams and Wardle 2004).

c) Competitive capacity – success of new plants

Pines can out-compete most native vegetation for water, nutrients and light in the regions in which plantations are grown (Burdon and Chilvers 1997, Richardson 1998, Lindenmayer 2002, Williams and Wardle 2007 a). As a result, pines can establish under most temperate vegetation but native species generally cannot establish under a dense stand of pines. The deep shade and heavy layer of pine needles and pollen cones that accumulates under and near pines also suppress establishment of competing understorey and overstorey species (Baker *et al* 2007)

d) Surviving to reproduce – adaptation to fire, pests and predation

An important factor in the success of *P. radiata* in locations outside its original range in California is that most of species that compete with it and its pests and diseases have been left behind. Its success and rapid growth rate may result largely from release from this biological burden (Burdon and Chilvers 1997).

Pines are also well adapted to survive and benefit from the natural disturbance that most commonly occurs within native vegetation – fire. While seedlings and young pines can be killed by a low intensity fire, a hot fire is required to kill mature trees (Lindenmayer and McCarthy 2001). Seed stored in cones is protected from fires and is shed after the fire has passed. Seed in the soil is also protected. After a fire freshly shed seed and seed in the soil seed bank can germinate. Seedlings establish quickly and benefit from the absence of competition and nutrients released by the fire. Only fires that are too frequent to allow pines to mature and produce seed will reduce pine density (Cheal 1994).

e) Naturalisation – maintaining the conquest

Naturalised plants are those that are able to maintain self-sustaining populations without direct intervention by people (Williams and Wardle 2007 a). Studies in the Blue Mountains of the density of pine wildlings within native vegetation found a clumped distribution, which showed that many younger wildlings were part of a generation derived from old established wildlings (Williams and Wardle 2004). A similar clustering of young pines around old pine wildling has been observed within native vegetation in many other parts of Australia. This evidence of the ability of pines to become a permanent feature of native vegetation is consistent with predictions that can be made from their 'vital attributes'. Unless controlled, pines, once established within native vegetation, lead to a new type of forest containing substantial density of pines will develop (Burdon and Chilvers 1997).

Thus, invasion of native vegetation by pines has two phases that impact on control **(**Williams and Wardle 2007 b):

First Phase – initial invasion: Establishment of wildlings

Second phase - naturalisation: First generation wildlings mature and begin to produce seed, leading to establishment of a second generation of pine wildlings.

2.2.2 Seed load

Propagule pressure, the amount of seed falling within native vegetation and for how long, is the major determinant of invasion at a local scale (Richardson 1998, Williams and Wardle 2004, 2007 a). Several factors influence seed load.

a) Proximity to major seed source:

The seed bank in the canopy of a mature pine plantation is massive (Richardson 1998). Windbreak plantings also provide seed sources on long fronts.

In SA a seed bank in the canopy of between 3.6 and 8.3 million seeds per ha has been measured in a mature pine plantation (Williams and Wardle 2007 a). While seed production varies with many factors, such as age of plantation, soil conditions and insect predation, land close to a mature plantation experiences a veritable rain of seed during the hotter months of the year. A result is that pine wildlings in nearby native bush can reach densities that are as great, or greater than, in nearby plantations (Richardson 1998).

Wind direction and intensity during the hotter months influences how far seed is carries and which vegetation is subject to the most intense seed 'rain' (Williams and Wardle 2004). Typical of a wind-dispersed species, numbers of pine wildlings falls off markedly within a few 100 m of the seed source, although Lindenmayer and McCarthy found no reduction in density of wildlings within 400 m of a plantation (Lindenmayer and McCarthy 2001). The 'rain' of seed was apparently so great that any diminution of its intensity over almost half a kilometre was insufficient to impact on establishment of pines.

A reflection of the importance of proximity to a seed source was observed in the Tumut region: continuous vegetation remote from pine plantations was substantially free of invading pines, while pine wildlings were common in remnants of eucalypt forests close to pine plantations.

Wind direction has a major influence on distribution of wildlings. A survey in the Blue Mountains showed that the number of pine wildlings was greatest on the south east side of plantations, consistent with prevailing winds during hotter and drier periods when seed is shed (Williams and Wardle 2004)

2.2.3 Passage of time

Typically invading plants have a period of slow invasion, followed by more rapid increase in their distribution and density. This may explode into high rates of invasion and impacts on the host landscape (Richardson 1998).

Based on the growth patterns of pines and the passage of time since pine plantations have been established, Richardson concluded that pine invasion is:

Set to increase dramatically over the next few decades if left unchecked, both in areas where invasions are already evident and in other areas with recent plantings over large areas. (Richardson 1998 p. 22)

2.2.4 Type of native vegetation

P. radiata can readily invade many vegetation types and both disturbed and undisturbed sites, but the vulnerability of vegetation to pine invasion varies (Williams and Wardle 2004, 2007 a). Vegetation with greater than 80% canopy cover shows much greater resistance to invasion than more open vegetation (Williams and Wardle 2007 a). Invasion is facilitated by disturbances such as fire, fire trails, logging (selective and clear-fell), and tree fall (Cheal 1994, Richardson *et al* 1994). Even vegetation that presents a high degree of resistance to invasion can be overwhelmed by a high enough seed load.

In the localities where most plantations occur the moderate rainfall and often indifferent soils result in more open vegetation types that present little resistance to invasion. Invasion by pine wildlings has been observes in (Cheal 1994, Richardson *et al* 1994):

- Dry and moist eucalypt forests and woodlands.
- Heathland vegetation.
- Woodlands with heathy understorey.
- Lowland grasslands and grassy woodlands.
- Riparian vegetation.

3 Impacts of pine invasion on native vegetation

3.1Consequences for biodiversity and ecosystems services

Invasion of native vegetation by exotic *Pinus* species has been reported in most countries where plantations are grown (Williams and Wardle 2004). *P. radiata* infestations of a thousand stems per hectare have been measured in native forests near old plantations in south western Victoria (Cook and Pratt 2008). As indicated earlier, once pines start to form a canopy they prevent the establishment of Eucalypts and other native species under them. In the absence of active control or fires frequencies greater than those appropriate to native eucalypt forests and woodlands, the passage of time will see the new Eucalypt – pine forest dominated by pines with only a few native plants surviving (Burdon and Chilvers 1997). The native forest has, in effect, become a pine forest, providing a totally different environment from the natural forest.

P. radiate is listed in the report of the Victorian Parliamentary Inquiry *Weeds in Victoria* as widespread in medium to large populations within many types of native vegetation, and presenting a very serious threat to a number of vegetation association (Environment and Natural Resources Committee, 1998, pp. 246, 250). A recent publication of the Collaborative Research Centre (CRC) for Australian Weed Management lists *P. radiata* as a weed with the following characteristics (Randall 2007, pp. 7, 373)

- Naturalised within in Australia.
- Recorded as a weed of the natural environment within Australia.
- Recorded within Australia as escaping from cultivation.
- Recorded as a weed of agriculture in some countries.
- Declared as a noxious weed in some countries.
- Recorded as an *invasive species* within Australia.

The category *invasive species* is, in the terminology used by the CRC for Australian Weed Management:

> *The most serious criterion that can be applied to a plant and is generally used for serious high impact environmental and / or agricultural weeds that spread rapidly and often create monocultures.*

Impacts of pine encroachment into native vegetation may include:

- Sever competition with native vegetation.
- Reduced light below the dense pine canopy.
- Changed and simplified vegetation structure, species composition and biomass distribution, with loss of understory within dense wildling infestations.
- Reduced diversity of food for native fauns.
- Loss of hollows for shelter and breeding.
- Reduced and spasmodic food supply for animals.
- Soil surface dominated by pine litter, pine needles and pollen cones, which suppress understory vegetation and fauna that depends on native vegetation litter.
- Reduced water flows and penetration to ground water;
- Altered fire behaviour.
- Changed soil properties, including pH, organic matter, organisms and, water balance (Richardson 1998, Lindenmayer, 2002, Williams and Wardle 2007 a).

The result is that, where pines dominate, biodiversity and populations of native animals are greatly reduced. Ecosystem services provided by native vegetation are altered and substantially reduced. Baker *et al* (2007) found that pine litter, as well as the living trees, causes adverse impacts on native biodiversity.

3.2 Exponential growth.

Pine wildling density in native vegetation is likely to follow the typical pattern of successful invading species, that is slow initial increase in density and area of pine invasion followed by increasingly rapid increase in density and the extent of land invaded.

Studies in the 1970s within the Australian Capital Territory (ACT) showed pine wildlings had reached densities greater than 165 trees per hectare as a result of initial establishment in mid to late 1960s Dawson *et al* (1979). The authors predicted then that density would increase substantially as invading trees reached an age where they started to produce copious seed and a second generation of wildlings establishes. Factors such as fires, grazing by rabbits and commercial stock could also have restricted pine invasion, factors that have had less impact on many forests in recent years. Two decades later another study from the ACT confirmed this prediction. It found that pine wildling density increase fairly slowly in the first 10 years from their first establishment in 1957. During the next decade their density increased at five times the initial rate (Burdon and Chilvers 1997).

With the long time frame relevant to tree invasion, even for fast growing species such as *P. radiata*, long lag times are not surprising. This can have the effect, while the invasion is building up, of lulling humans into a false belief that there is no great problem. In addition, young pine wildlings can be obscured by native vegetation or be in locations seldom visited, so may go un-noticed while their numbers and size are building up. As a consequence, adverse impacts may be overlooked during the early stage when control is most cost effective and least damage has occurred (Richardson 1998, Williams and Wardle 2007 a).

4 CONTROLLING PINE WILDLINGS

The ecological of pine invasion provides the foundation on which effective control of pine wildlings needs to be built. Planning and implementing control is also influences by other considerations, which include:

- Primary goals and other objectives of managing natural vegetation.
- Safety.
- Density, size and accessibility of wildlings.
- Practicability.
- Potential future developments.
- Resource commitment.
- Political issues.

The last two factors influence what is possible, as much as do physical circumstances such as ease of access, steep terrain, or the vagaries of weather. In this paper we make no attempt to deal with these aspects of pine wildling control. We present options and factors that may influence choice of control methods, understanding that circumstances can vary so much from site to site that individual land managers must tailor control methods to their situation.

4.1 Implications of ecology

Principles that generally apply to control of exotic invaders include:

- Preventing establishment is better than weed removal as it involves less cost and disturbance to the natural vegetation and soil.
- Where invasion cannot be excluded, early control is most cost effective and causes the least impact on native vegetation.
- Naturalisation of the invader should be prevented by making sure that wildlings do not reach reproductive maturity.
- The seed source should be removed or limited

(Environmental Weeds Working Group 2007, Richardson *et al* 1994).

The aim of pine wildling control should therefore be to ensure pine wildlings remain at low densities and none reach maturity, and so become a source of further seed dispersal (Anderson (2008). Given the life cycle of pines, initial commitment of effort and funds for ten or more years is required to meet this aim. A commitment to on-going control will be needed as long as plantations of fertile pines are gown near native vegetation.

4.2 Implications of safety concerns and context

Several safety issues have been identified by public land managers in the Green Triangle region. Chief among these are discussed in this section.

4.2.1 Felling large wildlings using a chain saw

This can be a dangerous operation, particularly where there is a dense stand of wildlings or other trees near the large pine (Cook and Pratt 2009). Only highly trained and skilled operators should undertake this task. The area around largest trees should be cleared before the large trees are felled to reduce risk that they will be caught in other trees and not falling cleanly.

4.2.2 Felling saplings and moderate sized wildlings

Where these trees are in dense stands or tangled with Eucalypts they may not fall until other trees are cut, then fall unpredictably. To provide protection to the operator, a bob-cat with cabin and cutters can be used rather than chain saw (Cook and Pratt 2009).

4.2.3 Standing dead pine trees

Where large pine wildlings are killed by poisoning or ring-barking they may not fall for many years. These standing dead pines can drop limbs or fall without warning. Where there is likelihood of people frequenting the area, trees should be felled rather than left as standing dead trees (Cook and Pratt 2009).

4.2.4 Use of harvesting equipment

The option to harvest dense stands of larger pine wildlings is discussed below. This option reduces much of the safety problem of dealing with larger trees as harvesting equipment has very robust cabins (Moore 2008). On steep terrain all methods of removing large trees becomes more dangerous.

4.3 Control methods

This section deals with methods that can be used in the field to control pine wildlings. A check-list of factors to be considered when planning control of pine wildlings will include the following (Kasel *et al* 2005; Anderson 2008, Cook and Pratt 2008):

- Density of pines.
- Their size distribution.
- Maturity of wildlings – are they producing seed or will they do so soon?
- Further source of pine seeds.
- Type of area requiring control – native vegetation or seed source.
- Ease of access.
- Fuel load if fire is to be used.
- Surrounding land use and assets.
- Safety issues.
- Resources available.
- Condition of native vegetation.
- Other management that may be integrated with pine wildling control.

The main control methods and circumstances under which they are most applicable are listed in this section. Table 3 summarises the section.

4.3.1 Mechanical

Various forms of mechanical control are the main methods used in Australia (Kasel *et al* 2005, Richardson *et al* 1994). As pines have flexible stems, these are not broken by pushing, so this method is excluded. Those used depend largely on the size of the pine wildling.

Hand pulling is used for seedlings. The entire root system must be removed.

Cutting, using axe, hand or chain saw is used for saplings and smaller trees, with the equipment chosen depending on the size of the tree. Stems must be cut through fully below the first lateral branches to prevent regrowth. Larger stumps may be painted with herbicide to ensure that there is no resprouting.

Manual felling is appropriate for large trees at low density and smaller trees below harvestable size or density (Kasel *et al* 2005).

Harvesting of larger pines

Mechanical scalping of soil is suggested for rehabilitation of former pine plantations (Kasel *et al* 2005). This removes the soil seed bank and smaller pines. It will also remove accumulated organic matter and seeds of native plants, so is not likely to have much application in native forests. The exceptions may be where a dense stand of wildlings or a nearby plantation had produced a deep layer of pine duff (needles and pollen cones) that inhibit regeneration of native species.

Ring barking is used for larger trees, with or without painting the exposed cambium with herbicide.

Intensive grazing of land nearest to plantations may be used as a form of mechanical control where there is a dense infestation of seedlings (Richardson *et al* 1994).

4.3.2 Fire

The first point that needs to be made is that 'fire' is not one simple management tool. Its impacts and use depend on:

- Fire regime – frequency, intensity, season of application.
- The natural fire regime to which each vegetation type is adapted.
- The stage in pine control to which it is being applied.
- Other management objectives.

Effect of fire on pine wildlings can be mixed. While low to moderate intensity fire may kill smaller plants, it can also stimulate germination and establishment from pine seed stored in soil and shed by larger pines that are not killed and reduce competition (Lindenmayer and McCarthy 2001). As indicated in Section 4.1 d), hot fire is needed to kill large pines. Repeated burning is likely to be needed to achieve control where there is a store of seed in the soil.

Advice provided in a manual for plantation site rehabilitation (Kasel *et al* 2005) may be also appropriate for rehabilitation of sites that carry dense populations of large pine wildlings and, inevitably, substantial seed in the soil. In this manual a hot fire is recommended to kill larger trees. The fire must be of sufficient intensity to burn most of canopy of larger pines and low bark of large trees. Within native vegetation, cutting and pulling of smaller pine wildlings may be undertaken before control burn as dead pines increase highly flammable fuel.

Once large pines have been removed fairly frequent low-intensity fire can be used (Kasel *et al* 2005). Fire frequency of 4-5 years will eliminate smaller pines, deplete the soil seed store and prevent further recruitment from pines that mature within native vegetation Cheal (1994).

The suitability of fire as a tool to control pine wildlings depends, however, on the level of pine wildling infestation in the native vegetation. In heavily infested forest, where fire is aimed primarily at reducing the density of pine wildlings and removing reproductive wildlings, the use of frequent controlled burns is appropriate (Cook and Pratt 2006).

After the density of pines is reduced and the soil seed bank largely exhausted, the aim of fire management changes. Fire frequency then needs to match the natural fire regime to maintain native biodiversity. In south eastern South Australia fire is not used specifically to control pine wildlings within dedicated reserves. In this region sustained pine wildling control has kept the density and age of pines below a level where they have a large impact on vegetation communities and a natural fire frequency is required. In forests and woodlands this is 15-20 years, not frequent enough for it to be a major tool in pine wildling control (Anderson 2008). It is unlikely that natural fire frequency in any temperate vegetation would be frequent enough to be used as a major tool for pine wildling control. However, this is a subject on which there is a paucity of rigorous research for temperate Australian vegetation, and more work is needed.

It is possible that fire may have greater application in heathlands because of the usually greater natural frequency of fires in these ecosystems Cheal (1994). A good understanding of the fire frequency of specific heathlands is still needed to use this tool appropriately. Fire frequency that can prevent pines from seeding will also eliminate native species that regenerate only from seed and have a similar time from establishment to sexual maturity. Other considerations include season and intensity of fire: fairly hot fires are probably the natural type for heathlands, which provide a substantial fuel load. Research on this aspect of fire regime is scant.

Generally, fire must be used with great care as a management tool, and be done in parallel with monitoring and research into its ecological impacts. In addition, fire may be difficult to manage in small remnants because of risk to valuable plantations and other assets (Lindenmayer and McCarthy 2001).

4.3.3 Herbicides

As indicated in Section 8.1, herbicides may be used in conjunction with felling and ringbarking of trees. Stem injection is suitable for large, isolated trees (Kasel *et al* 2005). Foliar application of herbicides has been used on seedlings in disturbed areas near plantations (Richardson *et al* 1994). Monitoring is needed and follow-up control undertaken where this proves necessary (Kasel *et al* 2005)

- Problems with Chemical control include:
- Variable success rates.
- Seed still being dispersed from mature trees.
- Difficulty distinguishing treated from untreated trees during control operations.
- Delay in death until after contractors are paid and gone.
- Safety concerns where falling dead trees may cause injury

(Williams and Wardle 2007 a).

Table 3 Summary of pine wildling control options and circumstances under which they are applicable

Size	<1 m tall (smaller seedlings)	1-4 m tall	>4 m tall; diameter < 35 cm	Diameter > 35 cm
Circumstances	Options			
Moderate or low density, native veg. in good condition	Hand pull	Cut with axe, bow saw or chainsaw.	Fell with chain saw; may also paint stump with herbicide; If > 15 cm diameter possibly harvest for sale (See Section 9).	In unfrequented location, ringbark and paint cambium with herbicide; In frequented location, fell tree and leave to rot to remove hazard of falling tree or branches.
Dense, native veg, degraded and pine control highest priority.	Control burn; follow-up surveillance with hand pulling; further burn after 4-6 years.	Cut with bob-cat equipped with cutter.	Cut smaller stems using bob-cat: May harvest larger trees using second thinning equipment and / or mobile mill system.	Remove smaller trees by cutting and burning then: fell large trees and leave on ground; or ringbark and poison if in isolated location.
Program for long-term control	General points: Systematic to ensure full cover. Includes 10-12 years initial reduction of wildling density and removal of fertile pines followed by maintenance control. May make use of volunteers, particularly within reserves Stage 1 Remove largest emergent pines first as these are main source of further infestation. Stage 2 Remove fertile smaller pines, possibly harvest. Remove saplings and seedlings Stage 3 – on-going, approximately every 4 years. Surveillance and systematic control of young pines to ensure no wildlings reach maturity.			

Risks: With felling wildlings;	In dense stands, or where pines are tangled with Eucalypts, trees do not always fall when cut. Several trees may fall together in an unpredictable way that poses considerable risk to workers. Large dead pines left standing can fall without warning. They should only be left standing in isolated areas. Felling large pines is difficult and dangerous. It should only be done by highly trained and skilled operators.
With use of fire.	Only the hottest fires kill mature pines while fire leads to release of seed from cones so follow-up control is essential. Fires that effectively control young pines are too frequent to sustain native forests, so are only appropriate in early wildling control.
Indicative costs as at 2008	$2,000+ per day for 4 people, with area and pines removed depending on their size, density and proximity to access tracks. $5-24 per tree removed depending on density of infestations. $10 per hectare for maintenance control of small wildlings at low densities.

Sources: Cook and Pratt (2008), Geelen, L. (2008), Mengler *et al* (2008), Pratt (2008)

4.4 Option to harvest

An approach that was the subject of a trial within the Rennick State Forest in south west Victoria is the harvesting of larger pine wildlings (Cook and Pratt. 2008, Pratt 2008, Moore 2006). This may be appropriate where pine wildlings have remained unmanaged in native forests for several decades. Commercial harvesting may be an option for covering the costs of controlling dense pine wildlings.

A 6 hectare stand of pine wildlings within this forest was found to be of a suitable size and density for harvesting by equipment normally used for second thinning in pine plantations. The tracked harvester has low ground pressure and is manoeuvrable enough to minimise damage to native trees during felling and removal of pines. Pines were felled in July 2007. The result was 240 tonne of pulp wood and 240 tonne of millable logs ranging in diameter up to 350 mm. There remained 23 pine trees ranging from 350 mm – 600 mm in diameter that could not be harvested by the equipment used. They where manually felled in a 6 hour period, using a chainsaw. Costs of the whole operation were covered by returns from the harvest and damage to the native vegetation was much less that would have resulted from continued growth of the pines.

The site was subjected to control burnt in the following October. The Victorian Department of Natural Resources and Environment (DSE) is now monitoring the site and determining what follow-up control work will be needed. It is expected that this will mainly involve pulling out new seedlings, a fairly quick and simple job if it is done regularly and pine wildlings are not allowed to get away again.

Several factors influence the viability of this option. Mills in the region must have spare capacity to handle extra logs. This is commonly the case to allow for respond to increased market demand when the building industry is buoyant. The commercial viability of the option depends on demand for timber and wood chips. Returns to the processor must cover costs. Table 4 summarises factors that determine costs and so which stands of pine wildlings may be suitable for harvesting.

Returns depend on the market. Potentially, they could also be influenced by incentives if operators also undertake to remove smaller wildlings are also controlled.

Table 4 Factors influencing costs of commercial processing of pine wildlings

Stage in processing	Costs influenced by:
Harvesting	Size of tree – costs fall exponentially as volume of timber per tree increases. Volume of timber is a function of diameter and length. Tree diameter needs to be >140 mm for a length of at least 3.6 m, with total timber per tree averaging > 0.1 cub. m. per tree in a stand; Density of trees in the stand – cost also falls exponentially as density increases. Interaction between size and density
Extraction	Extraction costs fall initially as tree volume increases then rise again as trees becomes too large for equipment to handle trees easily. An optimum diameter is likely to be around 300 mm diameter, but will depend also on tree height. Terrain is important in some localities.
Haulage	Relates to distance and ease of access.
Milling	Low cost as overheads are already met.

Source: Moore (2006)

There is potential for private operators to harvest and mill pine wildlings from private forests using mobile mills: this could involve less difficulty with regulations than where harvesting is on public land. Largest trees may also be harvested and milled on site. Mobile mills might make the operation profitable for private owners of native vegetation. An incentive related to ecosystems services might be added if the land holder undertook effective rehabilitation of the native vegetation. This would be aimed at discouraging continued growing of wildlings for harvest and reward services to the wider community.

4.5 Monitoring and evaluation

Monitoring and evaluation need to be treated as an intrinsic part of pine wildling control. The aims may variously be to:

- Ensure contract and volunteer work has been carried out adequately.
- Assess outcomes of control effort.
- Guide the next control effort.
- Identify new pockets of invasion.
- Acquire new knowledge and improving control management

(Kasel *et al* 2005).

4.6 Volunteers

Government agencies managing public land in the Green Triangle make considerable use of volunteers to do pine wildling control (Anderson 2008, Mengler *et al* 2008, ForestrySA 2006). Volunteers vary in their levels of skill and commitment and so how they can best be used. In some cases their involvement is mainly aimed at education while with others it provides the main means of controlling wildlings.

Volunteers include:

- **Friends groups: t**hese are very reliable, some are highly skilled and they often have long-term and high levels of commitment. They do most pine wildling control in reserves within south eastern South Australia. They only require the collaboration of departmental staff, not their supervision.
- **Schools, Green Corp; etc.:** these provide short-term, less skilled work and need considerable supervision and direction. They can do safe tasks in readily accessible locations, mainly pulling seedlings.
- **Corrective services:** these are not strictly volunteers but fulfilling community service obligations. They also need a good deal of direction and supervision, though may enjoy the vigorous outdoor work

(Lindsay 1998).

Volunteers provide an invaluable service, but it is essential to appreciate that this service is not free. Nor is it suitable for large areas remote from substantial population centres. If effective use is to be made of volunteers there must be an adequate and reliable budget to meet the costs of making use of their generous service. The budget must cover:

Planning, organisation, communication, supervision and monitoring by paid agency staff.

Insurance for volunteers.

Agency staff seeking funding to cover volunteers' costs, such as transport, training, equipment and refreshments.

5. Reducing weed potential of plantations

One set of options that may be developed in the future relate to reducing or eliminating the source of pine seed. The one most often proposed is breeding sterile pine cultivars. An alternative is biological control using insects that attack pine seed (Richardson 1998). A second set of options has to do with planning, policy and market incentives.

5.1 Sterile pines:

Modern breeding programs focus firmly on commercial benefits, with emphasis more on wood quality than quantity. Quality has, over earlier breeding cycles, suffered at the expense of quality. Breeding policy is now aimed to achieve more growth of higher quality timber from trees that can tolerate a wide range of environmental conditions, including poor soils, and are resistant to disease (Wu 2007).

Superior stock is mass propagated using vegetative means so does not need to be fertile (Wu 2007). The important objective of retaining pines with genetic diversity as a resource for future breeding can be achieved without fertile pines in commercial plantations. Stocks are best maintained in pine orchards sufficiently remote from plantations and pine wildlings to avoid genetic pollution (Wu *et al* 2007).

Development of seedless pine clones has been underway in South Africa for more than a decade to produce infertile pine cultivars (Richardson 1998). There is little interest in Australia in sterile pines, but several considerations could encourage their development and use. The first is a growth advantage without loss of quality; the second is a market edge through production that can claim ecological benefits by reducing pine invasion of neighbouring native vegetation (Williams and Wardle 2007 a). A third advantage would result if a levy or other regulation to cover costs of pine wildling control were instituted. These should quite properly exempt plantations that use sterile plantation stock. Moore (2008) believes that, with sufficient interest, ten years could see sterile pines grown in most plantations.

5.2 Planning - buffer zones

Buffer zones have been proposed as part of the design of plantations. Baker *et al* found that a buffer of as little as 20 m around a plantation will significantly reduce the amount of pine litter in the native forest near the plantation (Baker *et al* 2007). This can reduce the direct impact of a pine plantation on the understorey vegetation near the plantation but does not remove the need for pine wildling control. Use of wider buffers of grazed land or other trees around plantations can be used to separate plantation from valued native vegetation, trap seed and reduce pine wildling invasion (Williams and Wardle 2007 a). A treed buffer would be most effective in trapping seed. It could contain plantings of fire retarding species such as Acacias or Casuarinas. It would be important that there species be non-invasive. A frequently burnt strip might also be used as a buffer. Build-up of pine wildlings that become a source of further invasion would be prevented by frequent fire (Williams and Wardle 2007 a).

Buffer zones should be within the land set aside for plantation development, not further reducing the area of remnant native vegetation.

5.3 Integrated and adaptive management

Integrated management reduces control costs and may be more effective than focussing on only one method or objective (Environmental Weeds Working Group, 2007). Several methods of controlling pine wildlings, control of more than one weed, or weed control and other objectives may be addressed at the one time. Other objectives commonly have to do with using fire to reduce fuel load or improve biodiversity. Integration may also relate to how workers are managed: e. g. integrating work of contractors and volunteers or providing work for fire crews in the wetter part of the year (Moore 2008, ForestrySA 2006).

A recent trial on integrated weed management has been conducted in the Rennick State Forest of SW Victoria (refer to Section 9). Where there are heavy infestations of Coastal Wattle and pines, control burns have proved effective in reducing both weeds and to stimulate growth of indigenous plants (Cooke and Pratt 2008). This and another approach to pine wildling control are described in Boxes 1 and 2 to illustrate how integrated management allows adaptation to different circumstances.

On-going monitoring, review and evaluation is part of a continual cycle of improvement through adaptive management (ForestrySA 2006). This can, and should be, integrated into management that ensures continual learning and improvement. A systematic approach to this process of learning by doing is intrinsic to environmental accreditation described in Section 12.2)

Box 1 Programs for wildling control in reserves within SE South Australia

Context:

Little or no adequate past control; pines are moderately dense but not so dense as to prevent access or ready location of largest pines; the aim is to reduce seed shed.

Stage 1 - Initial treatment

a) Remove major seed source:

Fell large emergent pines.

Engage private land owners near reserves in felling large emergent pines as well – requires good diplomacy.

b) Complete initial treatment:

Remove fertile smaller pines using axe, chain saw or bow saw – some commercial harvesting may be possible.

Use systematic approach (grid and GPS) to ensure full cover.

Stage 2 - On- going maintenance:

Cut saplings and pull seedlings.

Use systematic approach (grid and GPS) to ensure full cover.

Continued systematic monitoring and surveillance.

Repeated every 3-6 years to ensure no wildlings reach maturity and seed bank remains low.

Opportunistic destruction of seedlings and saplings with ecological burning every 15-20 years every

Source: Anderson (2008)

Box 2 Programs for wildling control in reserves within SW Victoria

Context

Where there are dense infestations of pine wildlings making access and felling of largest pines, difficult and dangerous without first removing smaller wildlings; there may be potential to harvest wildlings.

Stage 1 - **Initial treatment**

a) Improve access and remove most mature pines:

Small trees – fell using single cut with axe or saw.

Larger trees below commercial size – cut with bob-cat to provide protection from erratic fall of tangled stems.

Commercial size trees – harvest if economic or fell.

Burn site to kill small to moderate sized pines and reveal untreated pines.

b) Complete initial treatment:

Fell trees >350 mm diameter and leave 5-6 years to rot; do not burn as this delays rotting

Fell any other larger pines that have been missed in Stage 1a) and were not killed by fire.

Possibly undertake controlled burn after 4 years to destroy new seedlings and young saplings.

Stage 2 - **On- going maintenance:**

Seedling removal and surveillance combined with ecological burning at longer intervals.

Source: Cooke and Pratt (2008).

6 Costs and benefits

As indicated in the first section, invasion of native vegetation by exotic species has social and economic impacts as well as causing direct environmental damage. This is particularly the case where the invaders are allowed to become dominant. Costs include the direct cost of lost ecological services from native vegetation and intrinsic values of biodiversity (Environmental Weeds Working Group, 2007). Avoiding the costs of pine wildling invasion incurs the cost of control (Richardson 1998). Effective early control has the benefit of minimising control costs and retaining the benefits of native vegetation.

In New Zealand the Department of Conservation spends more money in some areas on control of pine wildlings than on any other weed (Williams and Wardle 2007 a). In the absence of control, feral pine populations will build up and expand creating a very expensive control problem and substantial degradation of native vegetation. Estimates from New Zealand indicate that control costs can escalate from NZ$2 to NZ$1,500 per hectare in 20 years (Williams and Wardle 2004).

6.1 Factors influencing control costs

The number and variations in factors that influence pine wildling control are such that it is not possible to be prescriptive about what costs might be involved in any given situation (Mengler *et al* 2008). Important among factors influence the cost of control are (Cooke and Pratt 2008, Mengler *et al* 2008):

- Density and size of wildlings.
- Potential to off-set costs by returns to harvesting.
- Availability of contractors or skilled volunteers.
- Ease of access.
- Coordination with fire management, other objectives or other groups (e. g. commercial pine growers, private owners, other government agencies.
- Frequency with which control effort is needed, which is influences by proximity of seed source and effectiveness of past removal of mature wildlings.
- Capacity to perform necessary follow-up control work to minimise future control costs.
- Accessibility is influenced by:
- Access tracks around all blocks of native vegetation.
- Amount of debris and density of vegetation.

In some regions factors such as steepness of terrain, waterways and track layout could be important.

Costs of effective control include regular surveillance to identify pine wildling infestation – approximately every 2-3 years prior to control and roughly 10 years after successful control.

Public land managers have indicated that it would be useful to develop a check list of factors that could be used to estimate costs of pine wildling control for any given location.

Generally control costs can be minimised where adequate and on-going funding is provided to ensure early intervention and to keep on top of the problem. Issues of retaining skilled workers may be addressed by coordinating control work across groups such as commercial pine growers, private owners and several government agencies so that there is sufficient work to ensure greater availability of experienced contractors.

Table 5 provides indicative costs and time for control of pine wildlings in the Lower Glenelg National Park. These are averages (rounded to nearest whole number) for late winter 2005 and relate to works undertaken after managed fire. Wildlings were removed using chainsaws. It should be noted that pine density varies considerably but is generally fairly low; the terrain is not difficult to work in, and following, fire would be reasonably open.

Table 5 Indicative costs and time for pine wildling control - Lower Glenelg National Park, 2005

Number of Pines treated	Person hours	Minutes per tree	Labour cost	Cost per tree	Total hectares treated	Pines per hectare (average)	Labour per hectare (min's)	Cost per hectare
85	82	58	$2,023	$24				
147	51	21	$1,266	$ 9				
320	66	12	$1,626	$ 5				
75	51	41	$1,267	$17				
627	**250**	**33**	**$6,182**	**$ 10**	**615**	**1**	**24**	**$10**

Source: Bone (2008)

6.2 Quantifying benefits

Methods used to model the non-market benefits of pine wildling control are outside the scope of this study. Some information on the direct commercial benefits of harvesting pine wildlings is available from the trial described in Section 9. Those involved emphasised that net returns will vary from site to site and time to time (Moore 2008). The trial has suggested two useful ways forward.

An economic investigation to develop a budget model based on known factors that influence cost of harvesting wildlings and potential returns. The model would provide a quick means of computing the commercial benefits of harvesting wildlings and the minimum survey measurements need run the model.

Combination of the above economic model with a remote sensing model to provide indications of locations where pine wildlings may be considered for commercial harvesting. The aim would be to divide native vegetation into 3 categories:

- Density and size of pine wildlings too low to be worth considering further;
- A section of the total area that needs further investigation to determine if it is worth considering for harvesting; and
- Density and size of pine wildlings indicate the location is definitely worth considering for harvesting.

For II, the options for further investigation could include expert air photo interpretation and a quick ground survey.

7 FUTURE RESEARCH

Based on a considerable body of research (Cheal 1994, Richardson *et al* 1994, Williams and Wardle 2004, 2007 a, b) and this review of published and unpublished information, we have compiled a list of high priority topics for further studies on pine wildlings.

1. **Ecology of pine wildling invasion**
2. Population dynamics of pine wildlings in different types of native vegetation, currently inferred largely from plantation pines and overseas work.
3. How ecology of invasion and impacts of pine wildlings is influenced by fire regime and other disturbances.
4. How ecology of invasion and impacts of pine wildlings are likely to alter with climate change, soil and fire regime.
5. How pine invasion impacts on fire regime.
6. How pine invasion in Australia impacts on native species recruitment in different vegetation types.

7.1 Controlling pine invasion

Based on greater knowledge of factors that influence invasion, develop better approaches to planning and managing plantations for reduced pine wildling establishment.

Field research and modelling to guide integrated fire management for pine wildling control and other management goals.

Ecological investigations into impacts of harvesting and other control methods on plants and soils leading to operational guidelines for wildling control.

7.2 Decision support models

A management support model that integrates all factors relevant to control methods and costs for a particular site and then provides guidance about appropriate management options, likely costs and survey information requires.

An economic model to assist decision making in relation to harvesting of pine wildlings.

An integrated economic and remote sensing model to assist locating and assessing particular patches of pine wildlings for harvesting.

7.3 Dealing with conflicting interests

A model to clarify the role of incentives, regulation and mediation in dealing with conflicting interests of plantation companies and the wider community. Context of this study would be the fact that benefits of wildling control are generally enjoyed by the wider community and individuals who do not do the control work. Similarly, those who benefit from the plantation production are largely not the people who benefit from control of pine wildling invasion.

Assess potential impacts of options such as additional payments for environmental services where wildlings are removed and site rehabilitated or charges for environmental services lost where no such rehabilitation is undertaken: include feasibility of quantifying changes in environmental services.

Determine how to inform and influence those who control decisions relevant to control of pine wildlings, I. e. how to get pine wildling management recognised as an issue where it matters and commitment to deal with the issue.

APPENDIX 1

Seasonal Averages

Source – Bureau of Meteorology, internet site http://www.bom.gov.au/climate/averages/tables/ca_sa_names.shtml, May 2008

Wind information is not collected at all weather stations. Because of this, data used has been taken from locations were there is a full record of weather information and this has been collected over several decades. Information on rainfall and temperature was used from Mount Gambier Aero as well as the older weather station in Mount Gambier itself as the latter does not have recordings for the last decade.

TEMPERATURE – MONTHLY AVERAGES °C								
Location	**Jan.**	**Feb.**	**June**	**July**	**Aug.**	**Annual**	**Period**[3]	**comment**
Maximum								
Penola SFR	26.2	27.3	14.0	13.6	14.7	**20.0**	1971-94	
Casterton	27.1	27.4	14.1	13.4	14.7	**20.0**	1957-2008	
Mount Burr FR	25.1	25.6	14.2	13.5	14.3	**19.2**	1957-94	
Mt Gambier PO	24.3	24.8	14.2	13.6	14.7	**19.1**	1861-52	Figures could be low c/f now as only to 1952
Mt Gamb. Aero	25.1	25.1	13.8	13.2	14.1	**18.9**	1942-2008	
Minimum								
Penola SFR	11.8	12.0	5.2	4.4	5.2	**8.3**	1971-94	
Casterton	11.8	12.1	5.6	4.9	5.5	**8.3**	1957-2008	
Mount Burr FR	12.1	12.6	6.0	5.2	5.7	**8.8**	1957-94	
Mt Gambier PO	11.7	11.9	6.2	5.3	5.7	**8.5**	1861-52	
Mt Gamb. Aero	11.1	11.6	5.7	5.1	5.5	**8.1**	1942-2008	
	Warmest		Coldest months					

[3] Date of data collection is included as data needs to be interpreted in light of changes to climate, particularly reduced rainfall over recent years and a trend to small increase in temperature.

Summary:

Mean maximum temperatures averaged over a month are highest in the months of January to March. Across the Green Triangle monthly maxima in these months vary between 24.3 ^{o}C and 27.4 ^{o}C. Maxima are lowest in the winter months, ranging from monthly averages of 13.2 ^{o}C to 14.7 ^{o}C. Monthly mean minima range from 11.1 ^{o}C to 12.6 ^{o}C in the warmest months to 4.4 ^{o}C to 5.7 ^{o}C in winter. From these data, it is probable that maximum seed shed by pines will occur in mid-summer to early autumn.

RAINFALL – MEAN MONTHLY AVERAGES ^{o}C

(mean used instead of median as heavy rain largely captured in groundwater rather than flood rain running to sea)

Penola SFR	24.2	20.8	81.6	101.9	99.7	**708.5**	1958-1994	median > mean; distribution skewed by very wet years.
Casterton	30.0	24.4	68.7	84.9	84.9	**652.4**	1956-2008	median close to mean.
Mount Burr FR	29.2	27.6	97.4	113.2	104.6	**786.5**	1924-94	median close to mean.
Mt Gambier PO	32.3	29.0	96.6	107.1	99.8	**774.9**	1860-1974	median close to mean; probably lower for recent years
Mt Gamb. Aero	26.6	26.0	83.8	98.8	93.0	**707.6**	1942-2008	median close to mean; reflects recent drier years...
SUMMARY	Rainfall is seasonal with wettest months and most wet days in late Autumn to early spring;							

Summary:

Mean monthly rainfall is distinctly seasonal throughout the Green Triangle, with generally lowest rainfall in summer, higher monthly averages from late autumn to late spring and highest averages in the winter months. Combined with warmer weather in the summer months, this pattern of rainfall ensures driest conditions in the warmest months and highest plant growth in spring to early summer. Late autumn and spring are the months when use of fire as a management tool may be both feasible and safe. Use of herbicides may be restricted by rain and low temperatures from late autumn to late spring.

WIND – predominant direction (>10% of recordings) and speed of wind (km/h) (mode and maximum) for warmest months*						
Location	**Time**	**January**	**February**	**March**	**Whole year**	**Summary - winds Jan-March**
Penola SFR	9 AM	SW-SE 20-20; 20-30	S-SE; 42% S-SE 10-20; >=40	S-SE; 32% S-SE 10-20; 30-40	NE, S, SE – no direction dominates 0-20; 30-40	SW-SE winds predominate, generally only of moderate strength
	3 PM	NW-W-S-SE; 45%SW-S; 10-30; >=40	NW-W-S-SE; 40%SW-S; 10-30; >=40	NE-W-S-SE; 40%SW-S; 10-30; 30-40	NW-W-S-SE 10-30; >=40	Predominantly NW-W-S-SE (not N-NE); mild to moderate; infrequently strong
Casterton	9 AM	E-S-SE; 26% SE; 20-30; >=40	S-SE; 28% SE; 20-30; >=40	W, SE; 23%SE; 10-30; >=40	N-W; SE – reflects switch in direction from summer dominated by SE to W-N in cooler seasons 10-30; >=40	SE winds dominate but only N-E uncommon; mostly moderate strength.
	3 PM	W-S-SE; no one direction dominates; 10-30; >=40	W-S-SE; 42% S-SE; 10-30; >=40	NW-W-S-SE; no one direction dominates; 10-20; >=40	N-E-S-SE – only NE-E uncommon; 10-20; .>=40	NW-S-E-SE winds predominate (only N-E not common); moderate wit a few strong winds
Mount Burr FR	9 AM	W-S-E-NE (very variable; all but N, NE) 10-30; >=40	W-S-E-NE; 21% SE 20-20; >=40	W-S-E-NE;40% S-NE 20-20; >=40	All but NE; no predominant direction	Morning wind varies a lot in direction and often quite strong
	3 PM	W-S; 31% from SW 20-30; >=40	W-S-SE; 50% S-SE 20-30; >=40	W-S-SE; 50% S%SE 20-30; >=40	W-S; 31% from SW 20-30; >=40	Predominantly W-SE and often quite strong; significant wind from all directions
Mt Gambier PO	9 AM	NW-W-S-SE; no direction dominates 0-10; >=40	W-S-SE; 33% SE 0-10; >=40	NW-W-S-SE 0-10; >=40	NW-W-S-SE 0-10; >=40	Morning winds vary a lot with only NE-E not frequent: Light to strong
	3 PM	W-S-SE; 28% from S 0-10; >=40	W-S-SE; 28% from S 0-10; >=40 0-10; >=40	W-S-SE; 24% from S 0-10; >=40 0-10; >=40	NW-W-S-SE; 23% from W 0-10; >=40 0-10; >=40	Predominant winds in hot months W-S-SE, light to strong.

Summary:

Stronger and more frequent winds during hotter months vary considerably in direction. In the mid afternoon (3 PM), when seed shed might be expected to be greatest, winds are only uncommon from the North to East. In mid morning (9 AM) wind direction is generally more variable, but NE to E winds still less common. Sites vary from one another somewhat in relation to both more common direction and strength. At all sites strong winds (>=40 Km/h) are experiences occasionally, and moderately strong winds (30-40) fairly often. Recordings at several locations in the Green Triangle indicate that the frequency and strength of wind is sufficient at periods during hotter parts of the year to carry pine seeds considerable distances. More commonly though, moderate winds (10-40 Km/h) will lead to the greatest load of seeds within 1 km of the source.

To the NE-E of the seed source lower frequency of winds from the NE-E may lead to a lower seed load at substantial distance from the seed source.

Information on specific sites is needed to determine if these are major take-off sites for wind dispersal; that is, particularly windy locations where there is native vegetation within a short distance down wind.

The Bureau of Meteorology notes that:

> *Wind is one of the most highly variable meteorological elements, both in speed and direction. It is influenced by a wide range of factors, from large scale pressure patterns, to the time of day and the nature of the surrounding terrain.*

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