VINEYARD BIODIVERSITY AND INSECT INTERACTIONS - Establishing and monitoring insectariums

retallack viticulture
wine growing for the future

Prepared for : GWRDC Regional - SA Central
(Adelaide Hills, Currency Creek, Kangaroo Island, Langhorne Creek, McLaren Vale and Southern Fleurieu Wine Regions)

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Cover image by Sandra Elliott

Disclaimer

1. INTRODUCTION

The ***'Vineyard Biodiversity and Insect Interactions'*** booklet aims to provide winegrowers with the knowledge and tools needed to gain a better understanding of the complex role of insect interactions, including both the impact of pest species and beneficials (natural enemies of vineyard pests) providing 'ecosystem services' in their vineyards.

A summary of existing information and techniques about monitoring vineyard dwelling arthropods has been collated, including the enhancement of habitat through the establishment of insectariums (vegetation which provides shelter and a food source to beneficial insect species), monitoring methodology, and pictures to aid in the identification of a range of insect species (both vineyard pests and beneficials).

This project follows on from a series of successful workshops that were held in McLaren Vale and the Barossa wine growing regions in 2010, which discussed the integration, establishment and management of vegetation species (including native grass species), to enhance biodiversity and 'ecosystem services' in vineyards.

These notes contain information that has been collated from existing material where possible, rather than 'reinventing the wheel'. This provides a valuable resource for growers, as currently available information has been collated into a single document.

Links to further reading have been provided for vineyard managers who are interested in researching a particular topic in more detail. Information about regional environmental initiatives is attached in **Appendix 1** and key articles are attached in their entirety in **Appendix 2.**

The material contained in this booklet will be presented at workshops (incorporating a practical session), in the Adelaide Hills, Langhorne Creek and McLaren Vale wine regions at the start of the 2011/1012 growing season.

These notes are divided into the following sections:

- **Sections 1 to 2 – Background information**
  - This section contains information about the importance of enhancing biodiversity in the vineyard.
- **Sections 3 to 4 – Plant species (insectariums)**
  - This section addresses the topics of biodiversity, insectariums and how to go about selecting appropriate plant species when establishing insectariums.
- **Sections 5 to 9 – Arthropods (vineyard pests and beneficials)**
  - This section addresses the topics of encouraging 'ecosystem services' in vineyards, integrated pest management options and the identification of arthropods (both pest and beneficial species) commonly found in vineyards.
- **Sections 10 to 12 – Reference material**
  - This section includes checklists and links to supporting resources (websites, references and key definitions).

The Grape and Wine Research and Development Corporation (GWRDC) provided funding for this project, through GWRDC Regional - South Australia Central, which incorporates the wine regions of Adelaide Hills, Currency Creek, Kangaroo Island, Langhorne Creek, McLaren Vale and Southern Fleurieu.

2. A FOCUS ON VINEYARD BIODIVERSITY

2.1. Recent workshops

A series of five workshops held by the Adelaide and Mount Lofty Ranges Natural Resources Management Board (AMLR NRMB) were presented in McLaren Vale and the Barossa wine regions in 2010, attracting a total of 96 participants. The workshops focused on assisting wine grape growers to enhance the biodiversity on their properties.

Integrating native biodiversity into vineyard production systems

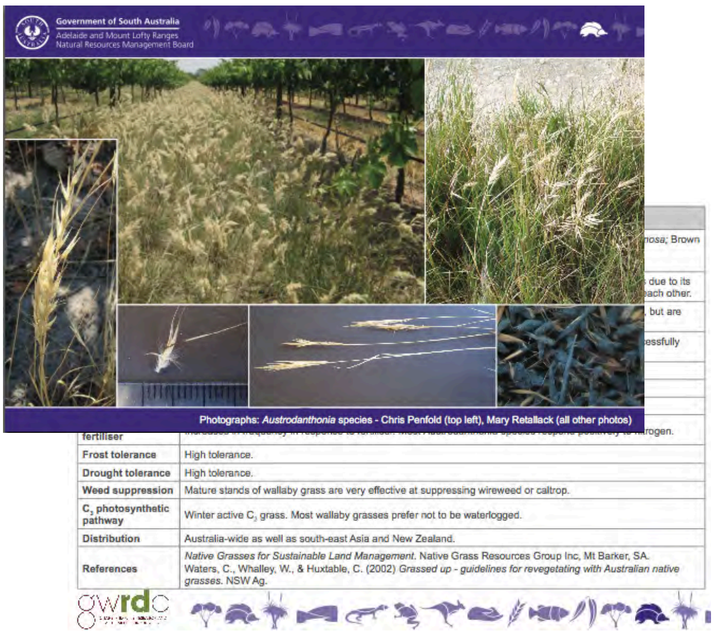
The workshops looked at the role of biodiversity in and around vineyards and focused on how to manage remnant vegetation, initiate revegetation projects and/or establish native grasses in appropriate areas. The workshop notes are available as a downloadable booklet.

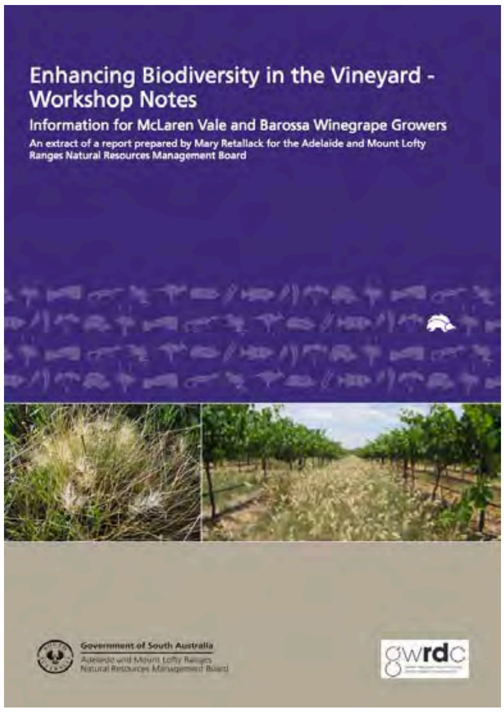
For more information about 'Enhancing Biodiversity in the Vineyard', go to www.amlrnrm.sa.gov.au/ then go to 'Publications and Resources', select 'Project Reports', then 'Land and Biodiversity Reports', then the '***Enhancing biodiversity in the vineyard – workshop notes for McLaren Vale and Barossa winegrape growers***' or press here. A series of ute guide cards for native grasses were also produced as a part of this project. To request a hardcopy of these cards contact your nearest AMLR NRMB office.

For vineyard owners who are interested in property planning and would like to attend an AMLR NRMB workshop, go to www.amlrnrm.sa.gov.au/ then select, 'land', then 'Land management advice', then click on 'landholder education'. To go directly to the information page press here. If you would like to get in touch with your local AMLRNRMB representative to organise a property visit press here.

To arrange for a property visit contact your nearest NRM board office:

- Gawler (08) 8523 7700
- Lobethal (08) 8389 5900
- Willunga (08) 8550 3400





The AMLR NRNB is working with vineyard owners to provide information and techniques to maintain native vegetation on property. For more information go to www.amlrnrm.sa.gov.au/ then go to 'Land', 'Support for industry' and 'Viticulture' or press here.

2.2. Why is biodiversity important?

An understanding of biodiversity (existing and potential) in the vineyard is an important step towards considering the complex range of interactions taking place between the flora (plant life including vines, cover crops, shelterbelts, hedgerows, beetle banks etc), fauna (animal life including larger animals, birds, insects, soil and aquatic organisms) and the natural balance of this environment. Biodiversity is a good indicator of the amount of variation of life forms within a given ecosystem.

Managing a vineyard means managing an ecosystem where grapevines are the dominant plant species.

The more genetically diverse these interactions are (quantity and variability), the better buffered and potentially stable, an ecosystem is said to be. For example, if a particular plant or arthropod species declines in a challenging season due to drought, flood, seasonal temperature fluctuations, or some other extreme weather event, then it is more likely that in a well-buffered system, another species will carry on with essential ecosystem processes. A sustainable ecosystem is more likely to be able to self maintain essential ecological processes and functions and as a result, it is more likely biological diversity will be maintained over time.

Figure 1: Biodiversity can be enhanced in a vineyard through both new and existing plantings.

The change in population dynamics can be demonstrated by the role of beneficials (the natural enemies of vineyard pests), which undergo changes in abundance throughout the growing season, with each beneficial species contributing to a greater or lesser degree to overall pest control.

For example *Trichogramma* wasps tend to parasitise Light Brown Apple Moth (LBAM) eggs late in the season, other wasp parasitoid species of LBAM larvae may be more abundant from mid-late season. Insect predators such as lacewings (green and brown), damsel bugs and spiders may be more abundant in early spring and summer, and a range of different spider species will be abundant throughout the growing season.

A system high in biodiversity tends to be more resilient against change. The more complex the system is, the better buffered it is likely to be and the more able to adapt to a change in its dynamics.

In the past, vineyards have been traditionally developed and managed as a monoculture (a single crop or species grown over a large area) and this will inevitably lead to instability within the system.

For example, when all plant or animal species regarded as a threat to vine health (or productivity) are removed, this will have an impact on the natural balance of the system (including the populations of beneficials), and may ultimately have a negative impact on vine health. This can be seen by the impact of using broad-spectrum insecticides (the use of non-target chemicals will indiscriminately kill both pest and beneficial species), or the consistent use of herbicides to the point where a soil becomes sterile.

We have learned that the indiscriminate use of chemicals is not sustainable in the long term, with ecosystem health slowly declining. Over time, more and more intervention is required to remedy the damage caused, or combat the pests or diseases that ultimately dominate.

'When we kill off the natural enemies of a pest, we inherit their work'
(Carl Huffaker, University of California, Berkley)

There has been increasing interest in organic, biodynamic and/or 'minimal input' viticultural practices in recent years. This goes 'hand in hand' with the desire for wine grape growers to understand vineyard systems better and to work 'smarter' rather than 'harder'. For example, having an understanding of the range of 'ecosystem services' that are provided by arthropods (including beneficials arthropods and other microfauna), provides us with the knowledge to encourage their presence and reduce the chemical inputs that would otherwise be needed to manage pest and diseases in the vineyard.

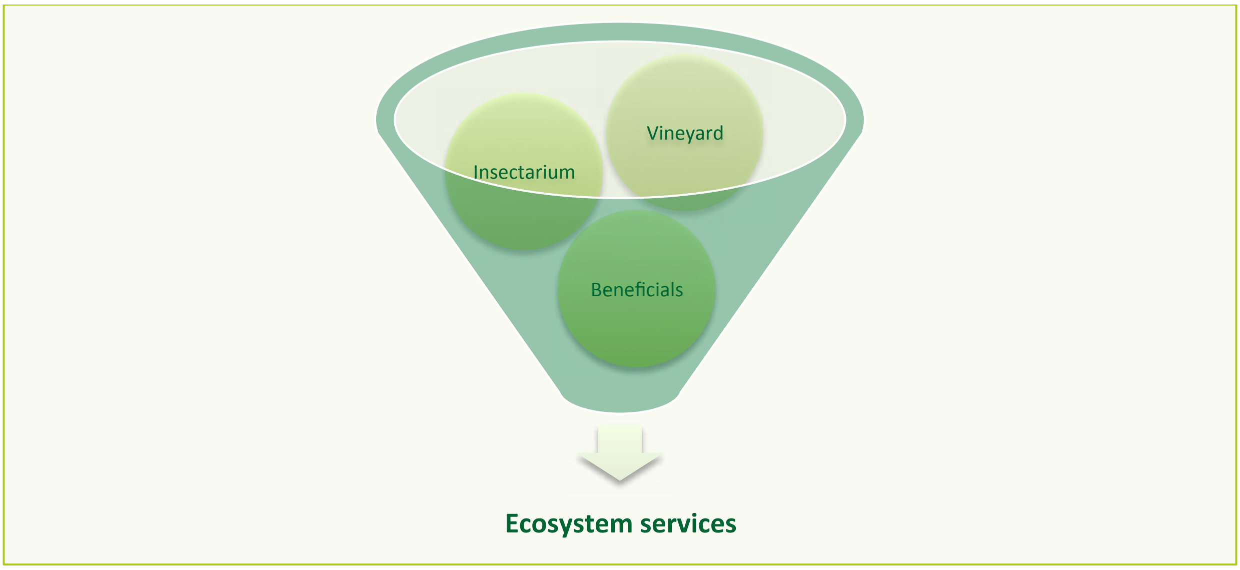


Figure 2: An insectarium can contribute to the role of beneficial 'ecosystem services' in the vineyard.

The diversity of arthropods present within a vineyard system has the capacity to provide a range of 'ecosystem services', which in turn has the potential to improve vineyard health in a number of ways. For example:

- Protection and enhancement of species diversity. It is less likely for a particular plant or animal species to dominate if there are many species keeping this balance 'in check',
- Attracting a range of beneficial species to the vineyard (territorial birds, beneficial insects, natural enemies etc) and as a result, potentially reducing the need for chemical pesticides,
- Provision of alternative food and shelter sources for beneficial organisms in the vineyard (wildlife habitats and corridors, shelterbelts, hedgerows and bug banks),

- Creation of shade and reduction of reflected heat (by applying mulch and species with a wide 'drip line') resulting in lower vineyard temperatures,
- Improved competition for dominant weed species (and a reduction in herbicide use),
- Improved plant protection through the stimulation of self-defence mechanisms,
- Improved soil health and structure, optimising nutrient cycles (by incorporating green manures and compost), and
- Recovery of the ecosystem from unpredictable events (extreme heat, rainfall, flooding, wind etc).

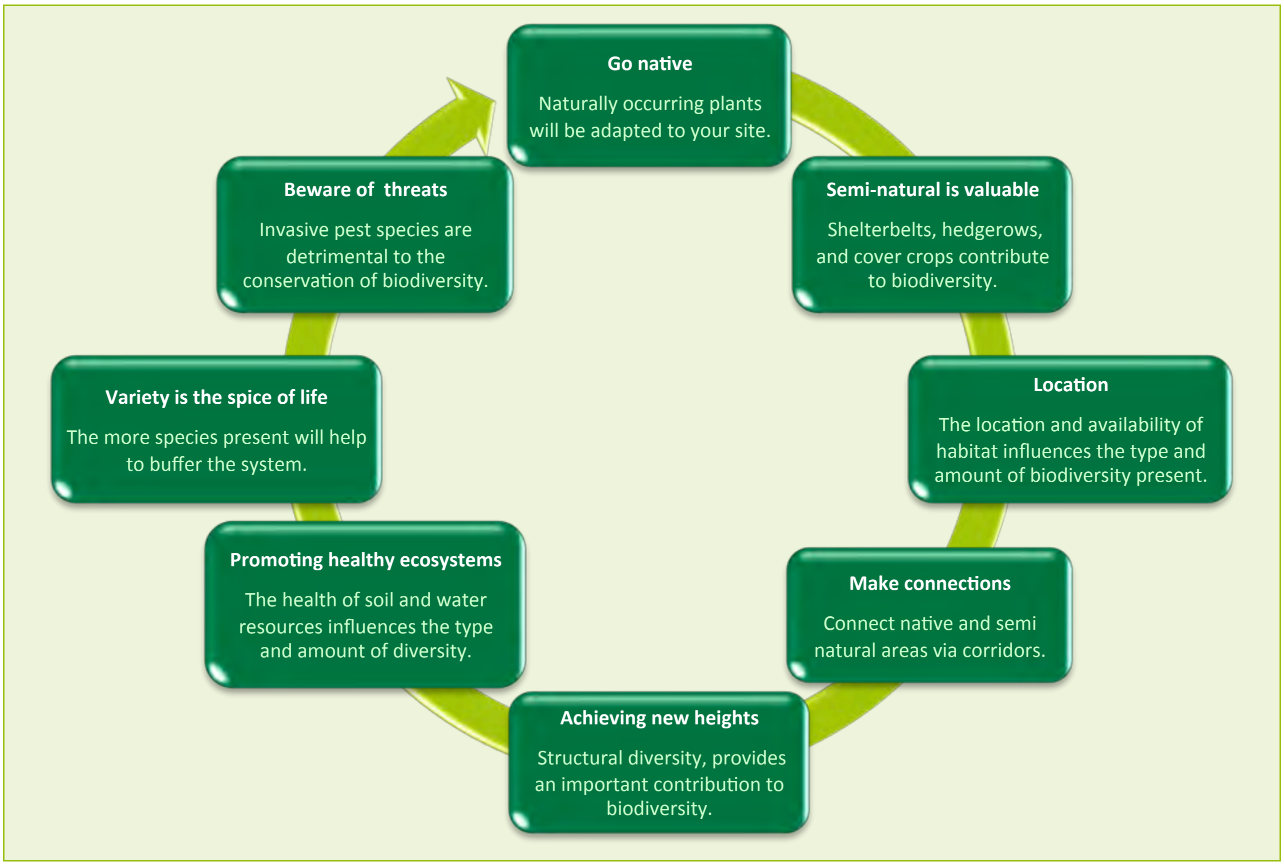


Figure 3: Ways of enhancing biodiversity within a vineyard property.

Different ways of enhancing diversity

A diversity of plants can be incorporated in and around the vineyard to help enhance the biodiversity present, in some cases undervine, via the mid row area, adjoining shelterbelts or hedgerows and via remnant vegetation that may adjoin the vineyard.

It is important that the 'right' species are selected which complements the vineyard, while providing the benefit of attracting beneficial species at the right time in the vineyard season. It is also important to select species that will not dominate or harbour pest species.

There are three main ways to consider the role of diversity in and around the vineyard. They include:

- ***Species diversity***

  Species diversity describes the variety of different plant, insect and animal species in an area. In a vineyard setting where grapevines are the dominant plant species, it is important to consider how the diversity of species within a vineyard can be maximised. By providing the right conditions it may be possible to encourage a range of arthropod species that can provide beneficial services in the vineyard.

- ***Genetic diversity***

  The variety of genetic information contained in individual plants, animals and microorganisms, forms the basis for resilience and adaptability. For example different clones of the same grape variety will perform differently on a range of different sites and soil types and will differ in their drought resistance, vigour and habit characteristics etc. Similarly, different arthropod species will provide different roles within the vineyard at different times of the year.

- ***Ecosystem diversity***

  The complexity within an ecosystem, the variety of habitats, biotic communities and ecological processes that are present are all examples of ecosystem diversity.

All of these processes (along with sound vineyard management practices) have the capacity to contribute to healthier vineyard systems. Some broad indicators of vineyard health are presented in Table 1.

Table 1: Indicators of vineyard health (modified from Altieri et al[1])

Indicator	Values	Characteristics
Grapevine appearance	Least desirable	Cholorotic, discoloured foliage with signs of deficiency
	Moderately preferred	Light green foliage with some discolouring
	Preferred	Healthy dark green foliage with no signs of deficiency
Grapevine growth	Least desirable	Poor growth, short canes, limited new growth, sparse canopy
	Moderately preferred	Uniform canopy, thin canes, some new growth
	Preferred	Balanced canopy with uniform growth and good fruit balance
Tolerance or resistance to stress	Least desirable	Susceptible, vines do not recover well after stress
	Moderately preferred	Moderately susceptible, vines recovers slowly after stress
	Preferred	Resilient, vines recover quickly after stress
Pest or disease incidence	Least desirable	Susceptible, vines are more likely to suffer pest and disease damage
	Moderately preferred	Moderately susceptible, vines are less likely to suffer pest and disease damage
	Preferred	Resilient, vines sustain low levels of pest or disease damage
Weed competition and pressure	Least desirable	Vines are stressed and overwhelmed by weed pressure
	Moderately preferred	Moderate presence of weeds exerting some competition
	Preferred	Vines are healthy and are not adversely impacted by weed pressure
Actual or potential yield	Least desirable	Vine yield and fruit quality is low in relation to vine capacity
	Moderately preferred	Vine yield and fruit quality is acceptable in relation to vine capacity
	Preferred	Vine yield and fruit quality is optimal in relation to vine capacity
Genetic diversity	Least desirable	Monoculture (single species is present)
	Moderately preferred	Several species are present
	Preferred	An abundant mix of species that complement ecosystem function
Natural surrounding vegetation	Least desirable	Surrounded by other horticultrual crops, no natural vegetation
	Moderately preferred	Adjacent to natural vegetation on at least one side
	Preferred	Adjacent to natural vegetation on multiple sides
Management system	Least desirable	Conventional agrochemical inputs
	Moderately preferred	In transition to organic, IPM or input substitution
	Preferred	Diversified, organic imputs, low external inputs

[1] Altieri, M.A et al (2005) Manage insects on your farm – a guide to ecological strategies. Sustainable Agriculture Network, Beltsville, MD. http://www.sare.org/publications/insect/insect.pdf

Creating healthier vineyards

Have you thought about the relationship between yeast biodiversity and insect activity?

Viticulture managers tend to concentrate their efforts on growing high quality wine grapes and they may not always think about how their vineyard management practices may impact on the winemaking process that follows. Winemakers may choose to ferment using existing native yeast populations, or inoculated fermentations (which can also be influenced by the nature of the organisms present on the grapes) and for these reasons, fermentation management begins in the vineyard.

A key factor determining the yeast species present on the surface of a grape is often related to the health of the berries, compared to the amount of fruit damage present. The leakage of sugar substrates, either through physical damage caused by insects, birds or invasive fungal species, or as a consequence of berry ageing and shrivel due to dehydration, enriches the food source for a range of different yeast and/or mould species.

The types of insects resident in the vineyard will influence their populations, on or near the fruit. Insects can harbour different types of moulds and bacteria, which is often dependent on their ability to survive on the surface of the insect. For example, microbes can be deposited on the fruit when it is visited by particular insects, and in doing so this will alter the population levels on the fruit[2].

The types of fungicides used in the vineyard will have an effect on the types of native yeast that can survive in the vineyard, as will the types of insecticides used that impact on the health of beneficials.

Figure 4: The range of fungi occurring in the vineyard will be influenced by its surroundings.

While these relationships are not directly related to the planting of an insectarium, they provide examples of the complexity of interrelationships occurring in the vineyard and how a multitude of vineyard management decisions, can impact on the final quality of the fruit and resulting wine.

2.3. Ways of enhancing biodiversity in the vineyard

There are many ways of increasing biodiversity within a vineyard. This can be achieved through the introduction of new and varied plant species, carefully selected to provide a range of benefits.

Vineyard scaping (or farm scaping)

The incorporation of plants in and around farming properties is often referred to as 'farm scaping' or in this case the incorporation of alternative vegetation in and around a vineyard property could be referred to as 'vineyard scaping'.

[2] Modified from http://enologyaccess.org Microbial Ecology, Wine Grape Ecology notes.

Areas suitable for 'vineyard scaping'

Think about the areas within your vineyard that would be suitable for incorporating alternative vegetation plantings, for example:

Vineyard production area

- Mid row and under vine areas,

Vineyard surrounds

- Headlands (non producing land required for machinery access),
- Borders (including wind breaks and shelter belts),
- Non-producing areas around infrastructure (sheds, winery, loading pads, water storage),
- Riparian zones along waterways (creek lines, rivers), and
- Land unsuitable for productive grape growing due to salinity, water logging or requirements for wastewater disposal.

Figure 5: Vegetation can be incorporated into vineyard properties in many ways.

Additional plantings of alternative vegetation

In a vineyard the incorporation of additional vegetation plantings may take many forms, including:

- The management of resident floor (volunteer weed) vegetation between vine rows, or by planting cover crops as a habitat management strategy, to encourage beneficial arthropods.
    - Selecting non-crop plants grown as strips or islands in the vineyard, whose flowers match the requirements of beneficials (high in nectar and pollen) and/or provide shelter.
    - Planting a diversity of cover crop species (either annual or perennial), in the same mid-row or in alternate mid-rows. Volunteer weed growth may provide pollen to beneficials but it is important they do not also harbor pest species such as LBAM on broad leaves etc.

These are complex relationships and research is currently occurring to try and determine the best species to provide positive relationships in a vineyard setting.

- Incorporating vegetation in areas near to the vineyard to meet the needs of beneficial organisms:
  - Retain areas of native vegetation around the edges of the vineyard,
  - Plant islands of flowering vegetation,
  - Plant different strata (heights) of vegetation (trees, shrubs, forbs, grasses etc) in and around vineyards (windbreaks, shelterbelts or hedgerows),
  - Design habitat networks (vegetation corridors) that connect properties and provide a 'roadway' for wildlife and beneficials to enter the vineyard from surrounding ecosystems, and nearby stands of natural vegetation.
  - Plant insectariums with a specific focus on providing food and shelter for beneficials and natural enemies throughout the growing season and providing overwintering locations during vine dormancy.

Figure 6: Volunteer weed growth may provide a source of pollen and habitat in the mid-row.

Other ways vineyard managers can enhance above ground biodiversity

There are many ways vineyard managers can encourage biodiversity in the property.

For example:

- Leave areas of remnant vegetation on the property untouched as habitat for plants and animals,
- Apply composted mulch or other soil amendments to enhance soil biodiversity,
- Slash cover crops to provide a mulch layer and contribute to nutrient cycling undervine,
- Reduce mowing to increase beneficial numbers, or mow alternate rows to retain a short stubble stand – this may act as habitat for a 'beetle bank',
- Think about how you can attract the right bird species. Territorial insect eating birds may help to patrol the vineyard, discouraging fruit eating bird species from entering,
- Introduce ground birds (chickens, guineafowl, ducks) to help control weevils, cutworms and other ground dwelling pests,
- Provide a source of water for territorial birds and beneficial insects (vineyard dam), and
- Where possible replace agrochemical applications with more resource efficient methods of managing nutrients and pest populations.

Figure 7: Vine prunings left undervine may provide additional habitat for vineyard arthropods.

Vineyards that host plentiful populations of beneficials

Characteristics of vineyards that host plentiful populations of beneficials include:

- Vineyard blocks that are small and surrounded by natural vegetation,
- Cropping systems that are diverse and plant populations in and around vineyards, that include perennials and flowering plants,
- The vineyard is managed organically or with minimal use of agrochemicals,
- Soils are high in organic matter and biological activity and where possible are covered with mulch or vegetation.

Considerations when aiming to increase vineyard biodiversity

Some of the key questions to consider when you are aiming to increase vineyard biodiversity include:

- How can I increase species diversity to improve pest management and make fuller use of resources?
- How can I extend the system's longevity by including a range of plants around the vineyard that assist in nutrient cycling and provide food and shelter for beneficials?
- How can I diversify my vegetation plantings so they are in different stages of succession?
- How can I add more organic matter to activate soil biology, build soil nutrition and improve soil structure?

Whenever you try a new management strategy, do your research and include a process of assessing the outcomes (keep a control area so you can compare).

3. INSECTARIUMS

3.1. What are insectariums?

Insectariums are groups of plants that provide a protective niche for natural predators by providing shelter, a regular supply of pollen and nectar and a water source for a range of beneficial arthropod species. Arthropods are members of the phylum 'Arthropoda' and are animals having an external skeleton, a segmented body and jointed appendages. This class includes insects, arachnids, and crustaceans.

If there is vegetation near vineyards (remnant or planted) there can be a significant increase in vineyard beneficials.

A successful insectarium will provide the following features for beneficials[3]:

- **Shelter** – Suitable shelter is needed for arthropods to overwinter during the dormant season and/or provide a safe dwelling location near grapevines during the growing season.
- **Nectar** – A reliable source of nectar will provide a carbohydrate energy source.
- **Alternative prey** – An alternative source of prey can be provided within the insectarium to maintain beneficial populations until they are needed in the vineyard.
- **Pollen** – Protein is necessary for egg production and can be provided via a high quality pollen source.

These elements will improve the longevity of beneficial insects and their capacity to reproduce.

The key requirements that beneficial insects need to prosper are;
__S__helter, __N__ectar, __A__lternative food, and __P__ollen (__SNAP__)[3].

What is the difference between nectar and pollen?

Nectar is a sweet substance produced by some plants to attract pollinators such as bees, butterflies and some species of birds. Bees collect nectar and make it into honey. In the process of collecting the nectar, pollinators transfer pollen from the anthers to the stigmas of female flowers.

Pollen is a fine powder of microscopic particles produced from the anthers of male flowers.

Figure 8: Examples of nectar (left) and pollen (right) production in the vineyard.

[3] Barnes, A.M, Wratten, S.D, and Sandhu, H.S (2010) ***Biodiversity in vineyards: worth the bother?*** The Australian and New Zealand Grapegrower and Winemaker, September – Issue 560. p 25-33.

What arthropod species will an insectarium attract?

Insectarium will attract a range of beneficials that have the capacity to provide 'ecosystem services' in the vineyard, including the enhancement of beneficial arthropod activity.

Recent research suggests a positive increase in the relative number of arthropods can be found for parasitoids up to 100m away and ground spiders up to 50m away (monitored in pitfall traps) from a shelter belt, remnant vegetation and/or insectarium[4].

Research has also identified that generalist predators in the vineyard, such as Brown Lacewings, Damsel Bugs, ground-dwelling predatory beetles and spiders, commonly found in mid-row grass can be aided by habitat provision. The provision of grass pollen can help predatory mite populations to thrive even when numbers of prey are low, thereby increasing potential predation and nectar is a vital food source for many insects, including adult parasitoid wasps, the larvae of which feed on LBAM larvae and other pests.[5]

Key beneficials

Ladybird beetles (along with lacewings) are one of the most visible and best-known beneficial insects that appear in vineyards. Both the adults and larvae are active generalist feeders. Young larvae will pierce their prey and suck out their contents and older larvae and adults will eat moth eggs, mites, thrips and other small insects. They will also survive on pollen and nectar in and near the vineyard.

Lacewings, Green Lacewing adults are easily identified due to their slender pale green bodies, large lace like wings and long antennae. The larvae are a predator of a wide range of pest species including thrips, mites, LBAM/Vine moth eggs and small larvae and mealybugs. The larvae have pinchers for attacking their prey. Green Lacewing larvae carry the debris on their backs and are known as 'junk bugs'. They will also eat their own eggs, which is one of the reasons why the eggs are suspended on long stalks to protect them from their siblings as they hatch! The adults feed on nectar, pollen, aphids and honeydew. Brown Lacewing adults and larvae are predators of a wide range of pest species. Brown Lacewing larvae do not carry debris on their backs like Green Lacewings do.

Spiders rely on a complex diet of prey and have the capacity to have a strong stabilising influence on them throughout the season. Spiders are generalist feeders and are commonly either ground dwelling (enjoying the cover of mulch or other soil plant covers) or will live in the canopy of the grapevine (orb weavers).

Ground beetles, predaceous ground beetles belong to a large family of beneficial beetles. They are generally nocturnal and shelter under plant litter, in soil crevices, under logs or rocks during the day.

It is important to select the right plant species to ensure they are not a host for pest species. Monitoring of arthropod activity will help to identify any issues early.

Additional information about vineyard beneficials is presented in ***Section 7.***

How much will an insectarium cost to establish?

This will depend on your budget! An insectarium can be established for as little as $200, and you can build on it each season as your financial resources and time allows. The main costs involved in establishing an insectarium are for the plants (tube stock or seed), plant guards and any initial maintenance (including irrigation and weed control) required to establish the host plants.

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[4] Thomson, L.J., Hoffmann, A.A. (2006) ***The influence of adjacent vegetation on the abundance and distribution of natural enemies in vineyards***. The Australian and New Zealand Grapegrower and Winemaker, 514. p 36-42.

[5] Bernard M., and. Wratten, S. D (2007). ***AgNote: Enhancing beneficial insects and mites in vineyards: providing nectar, pollen, and shelter in vine rows***. The Australian and New Zealand Grapegrower and Winemaker, 519 (April), p. 33-34

‘A cost benefit analysis of shelterbelt establishment’ was recently completed by Thomson and Hoffmann (2010).[6] The costs involved in setting up a shelterbelt may be different than setting up an insectarium, however this example can be used to identify a range of common variables, including whether grape growers undertake the project themselves or use a subcontractor, if the area is to be fenced etc. The examples given will help to highlight questions about how you may wish to proceed with your insectarium establishment. Private costings can be sought once you have worked out your preferred strategy.

Where should I plant the insectarium and how long will it take before I see any benefits?

Insectarium plant species can be planted in a diverse range of areas in the vineyard including in the mid-row (native grasses and introduced species high in pollen and nectar production), undervine and as discrete groupings of plants established near vines, at the edges of the vineyard.

The area of research looking at the role of insectariums and their effect on populations of beneficials and pest species is ecologically complex.

Species specific interactions between beneficials and plants need to be determined, along with the optimum mix and distribution of desired plant species within a vineyard, and the potential for these habitat plants to host other pests or diseases that may affect grape vines. The best way to decide where to carry out your planting is to talk to other growers who have had experience in setting up insectariums. Think about the long-term goals you wish to achieve and monitor your progress once the insectarium has been planted.

Planning your insectarium

Before you plant your insectarium, it is important to take some time to plan your project. Some of the things you may whish to consider include:

- **Look** to see which natural enemies and pests are currently present in and around your vineyard.
- **Biology,** learn about the biology of beneficial organisms and what they need to survive.
  - When are beneficials likely to attack certain pests? What are their key times of activity, and how far are they likely to travel?
  - What are the requirements of nectar and pollen foods (or other habitat types) for key beneficials?
  - What are the beneficials preferences regarding specific plant species and arrangements of insectarium plants?
  - Does the flower shape allow the insects to access nectar deep inside flowers?
  - If annuals are planted, are they fast growing and flowering within a few weeks of sowing?
  - If perennials are planted they should flower at times that are in synchronisation with the activity of natural enemies.
- **Create** an inventory of existing habitat and plant resources in and around the vineyard,
- **Match** the habitat and resource requirements of the beneficials, and
- **Establish** an insectarium by selecting the appropriate plant species and planting configurations.

[6] Thomson, L., Hoffmann, A. (2010) ***Cost benefit analysis of shelterbelt establishment: Natural enemies can add real value to shelterbelts***. The Australian and New Zealand Grapegrower and Winemaker, March – Issue 155. p 38-44.

Assessing the effectiveness of insectariums

Insectaries, shelterbelts and remnant vegetation established adjacent to vineyards should be structurally complex. Try and mirror the natural system using native species where possible, as these species are already adapted to the local conditions.

Figure 9: Native species are planted in groups in this insectarium.

Careful consideration must be given when introducing new species (flora and fauna) into an existing vineyard ecosystem to ensure there is a complementary benefit.

Increasing the biodiversity does not automatically guarantee a net benefit to the system.

By introducing the wrong species there may be a net decline in the health of the ecosystem and conversely, getting the right species to interact can provide tangible benefits.

The overall effectiveness of insectarium plantings can be assessed by looking at their capacity to attract beneficial species, their effect on pest species in the vineyard and the cost/benefit of establishment and maintenance compared with the benefits gained. These benefits may be a direct correlation with reduced pest incidence, chemical use and/or improved aesthetics and overall health of the vineyard ecosystem.

By monitoring arthropod activity it may be possible to determine the effects of:

- The relative number of different insects (diversity and population) visiting insectarium plantings before and after planting. Start monitoring arthropod activity prior to planting your insectarium so you can compare the difference.
- The activity of beneficials near the insectarium and then regular distances from the insectarium and into the vineyard.
- The visitation to and effects of different flowering plant species, densities or configurations of insectarium plantings.
- Visitation of beneficials and pest species at defined control points in the vineyard.

These observations can be captured in a range of data collection sheets contained in ***Section 8.8***.

3.2. Other ways of forming a suitable habitat for beneficials

In addition to insectaries, cover crops, shelterbelts and remnant vegetation, there are other ways to provide habitat for beneficials.

Beetle banks

Areas for predaceous beetles to colonise 'beetle banks' can be produced by slashing (rather than cultivating) mid rows, and retaining the stubble as habitat, slashing alternate rows, implementing 'non-travel rows' in the vineyard, or producing rocky areas (rock piles left over from vineyard establishment) to provide sheltering locations for a range of beetle species.

It is important to make sure the right species are attracted! Monitor the activity near 'beetle banks' by installing pitfall traps. Information about how to use pitfall traps is located in ***Section 8.4.***

Hedgerows

Historically hedgerows were used to confine livestock, define property lines, provide shelter from wind, provide food, medicine and fodder (game animals, fruit, nuts, herbs), and supply structural and fuel wood.

How does the role of a hedgerow relate to a vineyard setting?

Vineyard managers have been using different forms of 'hedgerows' in vineyards for years; they just take on different names because of their structure and purpose. For example, plantings of trees and shrubs are commonly planted as shelter or windbreaks or to provide nature corridors

Hedgerows are defined as lines or groups of trees, shrubs, perennial forbs (herbaceous flowering plants), and grasses that are planted along roadways, fences, field edges or other non-cropped areas.

Hedgerows can be multifunctional and by broadening our thinking about how existing plantings of shelter or windbreaks act, they can take on the broader functions of a hedgerow.

For example:

- Hedgerows tend to be multi layered with a mixture of low, medium and high strata vegetation levels,
- They can serve as habitat for beneficial insects, pollinators and other wildlife; provide erosion protection and weed control,
- They can serve as windbreaks, stabilise waterways, and buffer pesticide drift, noise, odors and dust,
- Act as living fences and boundary lines, and
- Help to increase biodiversity (and improve aesthetics around the vineyard).

Figure 10: Hedgerows can take on many forms and functions as seen here; roadside (left), property boundary (middle) and screen plantings/windbreak/drift buffer (right).

3.3. Selecting the right species to plant

There are examples of planting lists available for establishing insectariums overseas. We have access to a broad range of flowering plants in Australia that are thought to attract beneficials, but we do not have extensive knowledge of these relationships and how they apply to Australian vineyards.

Each vineyard situation is different and the desirable goals to be obtained will vary depending on the attributes of the site and management approach employed. Examples of the types of plants that may be suitable for inclusion in an insectarium are presented below. **These plant examples are not intended as an exclusive list and each situation needs to be assessed on its merits.**

It is a good idea to plant a small 'test' area when trying a new plant species, observe what grows well, monitor its progress regularly and observe its flowering activity and capacity to attract beneficial species prior to embarking on a large insectarium planting.

The process of plant selection may take some patience, trial and error, but ultimately should prove satisfying once you get the mix right.

Beneficial insect plants for the home garden

Some plant seed mixes are identified specifically for attracting 'beneficial insects'. For example, 'Diggers' www.diggers.com.au sells a packaged selection for the home garden that includes the following species.

Table 2: Beneficial insect plants marketed for the home garden.

Plants recommended for insectariums in the home garden			
Bronze Fennel *Foeniculum vulgare*		*Phacelia tanacetofolia*	
Alyssum sp		Cottage Salvia Blue *Salvia farinacea*	
'Psyche White' *Cosmos bipinnatus*		Queen Ann's Lace (wild carrot) *Ammi majus*	

While a traditional cottage garden may look nice and provide some of the attributes you are looking for, it is important to consider if these plants will meet your long-term requirements in a vineyard setting.

Insectarium species need to flower for long periods (and at the right time to gain maximum benefit).

Cottage garden species may be difficult to establish (fine seed), short lived (annual species), have a high requirement for water, or may not be hardy enough. However, some cottage species do work well and viticultural specific research has been carried out for Buckwheat, Alyssum and Phacelia in New Zealand (see notes below) and Queen Ann's Lace also looks promising due to its abundant small flowers that are suitable for beneficials to access the nectar and pollen produced[7].

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[7] Mike Keller (*pers comm*) 2011.

General beneficial insect plants for use in insectariums

Other flowering plants that may attract natural enemies are presented in Table 3. This list provides an example of the plant types recommended for helping to increase biodiversity in Oregon vineyards[8].

These species may be suitable for insectariums in our vineyards, but need to be tested for Australian conditions, assessed on their merit and rejected if they prove to be unsuitable.

Table 3: Non-native flowering plants which attract natural enemies.

Plants recommended for insectariums (general)			
Umbelliferae (Carrot family)			
Caraway *Carum carvi*		Bronze Fennel *Foeniculum vulgare*	
Dill *Anethum graveolens*		Queen Anne's lace (wild carrot)	
Compositae (Aster family)			
Blanketflower *Gaillardia species*		Goldenrod *Solidago canadsensis*	
Coneflower *Echinacea sp*		Sunflower *Helianthus annuus*	
Coreopsis 'moonbeam' *Coreopsis verticillata*		Tansy *Tanacetum vulgare*	
Cosmos sp		Yarrow *Achillea sp*	

[8] http://www.sare.org/publications/insect/insect.pdf and http://winegrapes.wsu.edu/Perennial%20Plant%20List%20for%20Vineyards.pdf

Plants recommended for insectariums (general) - continued			
Legumes			
Vetch *Vicia benghalensis*		Sweet clover *Melilotus albus*	
Brassicaceae (Mustard family)			
Alyssum sp		Yellow rocket *Barbarea vulgaris*	
Other species			
Buckwheat *Fagopyrum esculentum*		Cinquefoil *Potentilla erecta*	

Beneficials with short mouthparts (eg tiny parasitic wasps), find it easy to obtain nectar and pollinate plants from the types of plants listed above because of the small, shallow flowers these species provide.

Plants that possess nectar sources outside the flower, such as faba beans and vetch, provide beneficials with easy access to the nectar and pollen of their flowers[9].

Taltarni Vineyards in Victoria have trialled the use of a range of species when establishing their insectariums. Some plants have not succeeded while other species have prospered. Comments for the species that have done well are listed below [10].

Table 4: Introduced plant species planted by Taltarni Vineyards.

Plants trialled for Taltarni's insectariums	
Common Name	**Comments**
White alyssum	A mass of tiny white flowers grew that provided nutritious nectar.
Clover species (rose clover)	Is a highly productive self-regenerating clover. Flowers 105 days after emergence.
Phacelia tanacetifolia	Grew very well producing fluffy lavender flowers that are a magnet for bees and beneficial insects.
Poppy Flanders Field	Grew a wonderful wildflower that is a joy to look at and attracted beneficial insects that visit our insectarium.
Queen Anne's Lace	Grew a white umbrella flower favoured by discerning beneficial insects.

Taltarni Vineyards are now trialling a number of native species in their insectariums, see Table 5. This provides an example of the types of plants that may be used. While these species may be Australian natives, they may not be local to your particular region. If origin is important to you, check the provenance of the species and/or the seed/tube stock supplied prior to planting.

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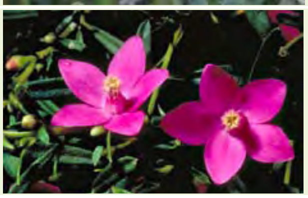
[9] http://attra.ncat.org/attra-pub/PDF/farmscaping.pdf

[10] Ludvigsen, K. and Bailey, M. (2009) ***Vegetation corridors in established vineyards.*** The Australian and New Zealand Grapegrower and Winemaker, 543. p 17-20.

Table 5: Australian native plant species currently being trialled by Taltarni Vineyards.

Examples of Australian native plants which may be suitable for insectariums (general)			
Needle Wattle *Acacia rigens*		Narrow-leaf or Slender Bitter-pea *Daviesia leptophylla*	
Broom Heath-myrtle *Babinonia behrii*		Sticky hop bush *Dodonea viscosa*	
Fringe myrtle *Calitrix tetragona*		Coccid Emu-bus *Eremophila gibbifolia*	
Scarlet bottlebrush *Callistemon rugulosus*		Heath or Silky Tea-tree *Leptospermum myrinoides*	
Sticky Cassinia *Cassinia uncata*		Rough-barked Honey-myrtle *Melaleuca parvistaminea*	
White correa *Correa alba*		Common boobialla *Myporum insulare*	
Small crowea *Crowea exalata*		Coastal rosemary *Westringia fruticosa*	

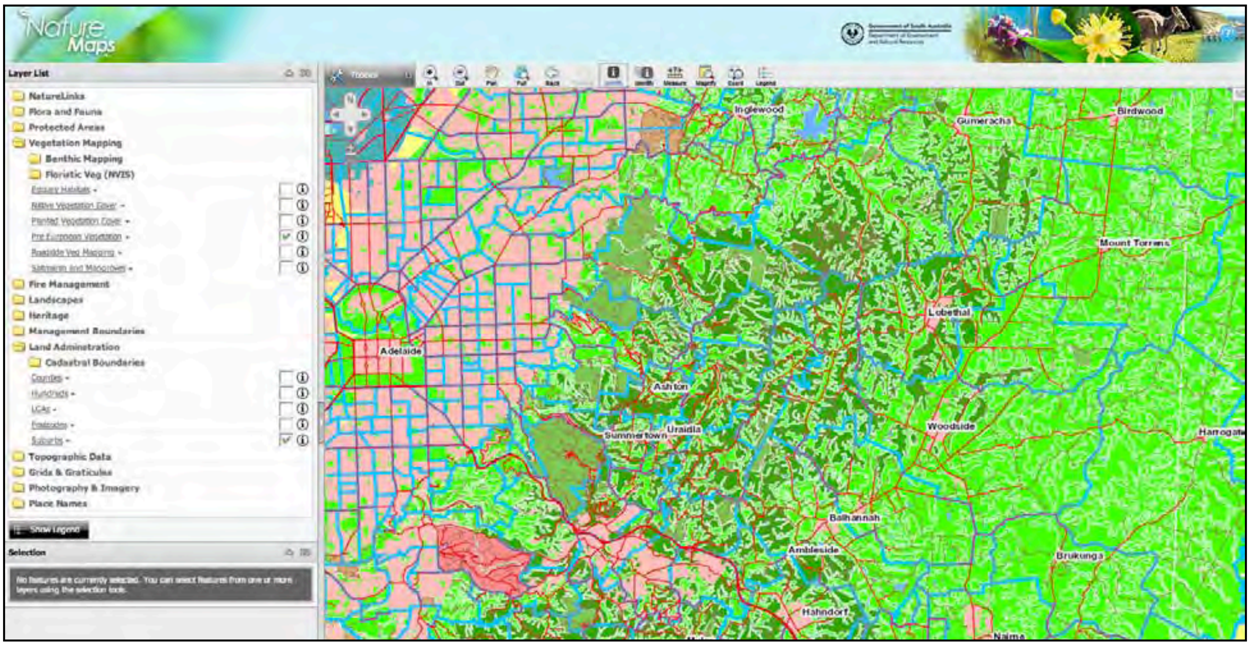
The **'Australian Native Plants Selector'** program enables the selection of Australian native plants to suit specific requirements (search for nectar and insects), for more information go to http://anpsa.org.au/download.html#query. To access the Australian Plants Society, SA Region website go to http://www.australianplantssa.asn.au.

Further information about local nurseries that supply native species go to www.environment.sa.gov.au/stateflora

Native plants that typically produce abundant, nectar-rich, easily accessible flowers in massed inflorescences include Angophora, Bursaria, Callistemon, Corymbia, Epacris, Eucalyptus, Grevillea, Kunzea, Leucopogon, Leptospermum, Melaleuca, Pimelea and Westringia.

Nature Maps – Getting information about local plant communities in your area

If you are interested in obtaining an indigenous plant species list that is appropriate for your property, go to http://www.backyards4wildlife.com.au/index.php?page=nature-map-instruction and follow the directions provided on the website.



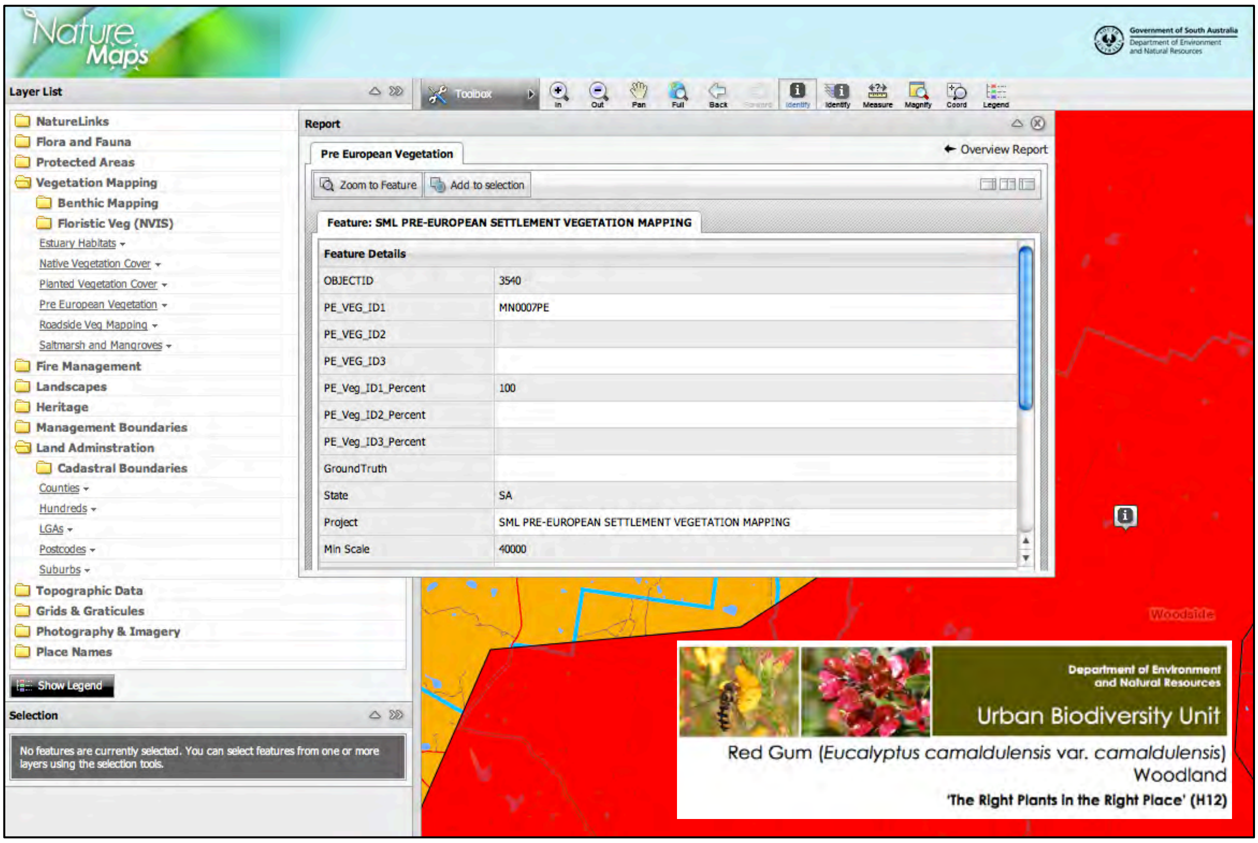


Figure 11: Nature Maps demonstration.

Once you have identified the vegetation association of most interest to you, download the appropriate species list by going to http://www.backyards4wildlife.com.au/index.php?page=hills-master-lists-2-2. This list can then be assessed for species that may suitable for establishment in an insectarium.

The use of native grasses in vineyards

Chris Penfold's research on the establishment of native grasses in vineyards identified the positive impact Wallaby Grass in particular, has on enhancing populations of beneficial arthropods in vineyards when compared to ryegrass.[11] Native grasses can provide a shelter benefit like 'beetle banks' while providing grass pollen as food for beneficials.

Table 6: Examples of Australian native grasses that may be suitable for insectariums.

Examples of Australian native grasses which may be suitable for insectariums			
Wallaby grass *Austrodanthonia species*		Kangaroo grass *Themeda triandra*	
Brush wiregrass *Aristida behriana*		Spear grass *Austrostipa species*	
Windmill grass *Chloris truncata*		Weeping rice-grass *Microlaena stipoides*	

A series of 'ute guide' cards for identifying native grasses that can be used in and around vineyards was recently produced as a part of the 'Enhancing Biodiversity in the Vineyard' project mentioned earlier.

To request a hardcopy of these cards contact your nearest NRM board office, or to download a copy of these cards press here.

[11] Penfold, C. (2010) ***Native grass cover crops.*** The Australian and New Zealand Grapegrower and Winemaker, March – Issue 155. p 48 – 50.

Vineyard specific research

Greening Waipara: Bringing practical biodiversity to the world[12]

An example of viticulture specific research looking the benefit of insectarium plants is the Greening Waipara Project, which has focused on the role of Buckwheat, *Phacelia* and *Alyssum* in New Zealand vineyards. For more information go to http://www.waiparawine.co.nz/research/greening_waipara

Table 7: Examples of high value insectarium species for use in vineyards.

Examples of introduced species suitable for vineyard insectariums		
		
Buckwheat *Fagopyrum esculentum*	Phacelia *Phacelia tanacetofolia*	White alyssum *Alyssum sp.*

Vineyards in the Greening Waipara project are encouraged to establish buckwheat and flowering plants such as *Phacelia* and *Alyssum* between vine rows, in order to encourage beneficial insects such as parasitic wasps to take up residence and attack predators, such as caterpillars and mealy bugs. If a parasitic wasp is able to have access to **S**helter, **N**ectar, **A**lternative food, and **P**ollen (SNAP) research has shown it is possible they may live up to ten times longer than normal.

Sowing every tenth row has been demonstrated to be effective in managing caterpillars to below the threshold normally required for spraying with conventional pesticides.

Buckwheat is so far the best source of nectar for vineyards. Phacelia is also suitable but its utility is not as high as that of buckwheat. Both were tested on the most abundant LBAM parasitoid in Australian and New Zealand vineyards, the Australian native wasp *Dolichogenidea tasmanica.* White alyssum, a drought tolerant self-sowing annual, is a good nectar source for the minute parasitoid of LBAM eggs *Trichogramma carverae*. It is low growing and well suited to under-vine planting[13].

How to use buckwheat (Bernard and Wratten 2007)[13]

Spacing. Nectar source in 1 of every 10 rows (25m) results in no decline in LBAM parasitism across rows.

Sowing and agronomy. Direct-drill (2 cm deep) early November and up to twice more in off set rows at three week intervals, at a rate of 45kg/ha (0.5 kg/100m row). The cost of seed in New Zealand is about 67c/kg, this means 34c per 100m of row. Water-in after drilling (again if very dry), but the plant is otherwise drought tolerant. All cultivars are suitable. Buckwheat takes only 5 weeks to flower (November planting), or 3 weeks (Jan/Feb planting).

What is happening in Australia?

'In-field Ag' based in the Adelaide Hills, have designed a machine which sprays out the mid-row weeds while sowing buckwheat in one pass. For more information visit www.infield.com.au.

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[12] Smith, M. (2010) ***Greening Waipara: Bringing practical biodiversity to the worl***d. Australian Viticulture, January/February V14, No. 1.

[13] Bernard M., and. Wratten, S. D (2007). ***AgNote: Enhancing beneficial insects and mites in vineyards: providing nectar, pollen, and shelter in vine rows***. The Australian and New Zealand Grapegrower and Winemaker, 519 (April), p. 33-34

4. PLANTING YOUR INSECTARIUM

4.1. Getting started – planting your insectarium

One of the first steps in enhancing the conditions for the survival of beneficial species is to reduce (or preferably omit) the use of harmful chemicals, while concurrently increasing the availability of pollen and nectar to complement existing food sources; and providing shelter to encourage beneficials to move to where they are needed, in close proximity to the vineyard.

Aim to provide a complex mix of flowering plants that will appeal to a large number and diversity of beneficial species at key phonological growing stages of the grapevine as well as throughout the entire season.

General guidelines

If time or resources do not allow for a detailed planning process, the following list may help you decide on the appropriate insectarium species to plant.

- Is the plant species likely to be a suitable host (providing pollen and nectar which is high in sugar and shelter) for a range of beneficial insect species?
- Which species are going to provide a continuous flowering period at key times during the growing season?
  - Which species are likely to be flowering at times to coincide with vineyard requirements ie encouraging beneficials to control LBAM up to and during grapevine flowering?
  - Many species are prolific seed producers. Are the species selected likely to spread and become a problem weed?
- Will plants be easy to grow, manage and not require a high water input?
  - Native species are already adapted to the local conditions and may prosper in difficult conditions,
  - Will introduced species be hardy enough to survive the local conditions?
- Perennial systems are more stable (and less work) than annual systems.
  - If annuals are planted are they self-regenerating?
- Bigger and interconnected patches of flowering plants are better than small patches, although benefits can be derived from small patches also.
  - Think about which species are more suited to light traffic areas, shelterbelts, vegetation corridors, mid-row cover crop, and insectarium specific plantings in close proximity to the vineyard etc.
- Variety is the key; maintain a diverse range of flower types, colours, plant structures, perennials and annuals.
  - Many of the flowering species can be used as 'cut flowers' and many of the herb species have additional medicinal qualities and/or can be used for a range of uses.
- Think about the shape of the flower (the nectar and pollen resources) and the insects relying on them.
  - Nectar in long flowering parts is accessed primarily by insects with log mouthparts such as bees and butterflies. Florets with small, shallow flowers are generally better for smaller beneficial insects.
- It is important to select species that will not harbour grapevine pests.

Spacing

The spacing of plants (to mimic natural surroundings) is important. For example, native grasses often grow as tussocks and need room to expand radially. It is not appropriate to plant a native grass cover crop with a similar planting density to that of an introduced pasture species.

Similarly it is important to have a feel for the type of spacing needed between insectarium, native vegetation stands or other vegetation on the property designed to boost the populations of beneficials in the vineyard. For example:

- The average travel distance for insects has been found to be 50 to 100m (extended with wind assistance), depending on the species. You may wish to plant additional vegetation to make corridors that will facilitate beneficial populations in and around a vineyard.
- At the Schillings Vineyard (owned by CA Henschke and Co), *Bursaria* (Christmas Bush or Sweet Bursaria) is planted every 20 metres in the headlands (next to strainer posts), and *Lomandra* (iron grass) will be planted every 20m throughout the vineyard (under vine and next to intermediate posts) in the future.
    - These species flower during the months of November and December, which is the time beneficial insects are needed to biologically control LBAM and other pest species in the vineyards.
- Research from Lincoln University in New Zealand suggests planting buckwheat strips (1 in every 10 rows), provides sufficient high quality nectar and pollen for beneficials throughout the vineyard.

Setting yourself up to succeed

Once you have decided on the species you wish to plant (and the best method of planting), make sure you set your project up for success by incorporating the following features.

- Ensure insectarium plantings are not sprayed with any pesticides (or drift from nearby vineyards),
- Depending on you location and the species planted, you may need to irrigate the insectarium to get it started (and/or maintain optimal plant health during periods of prolonged drought).
    - In addition, the application of mulch will suppress weeds and conserve moisture (however, some native plants have a low nutrient threshold and may not be suited to mulching).
- If you are considering planting trees, avoid fruiting species that may become hosts for pests such as fruit eating birds,
- Many species will have an extended flowering period, if pruned or mowed after becoming established. Consider planting beds the same width as your slasher,
- Wildflower seed mixes (often comprise a mixture of self regenerating annual and perennial species) can be broadcast by hand in Autumn (when soil temperatures are still warm and there is adequate moisture) or in early Spring, when soil temperatures warm up again.
- Include rocks in or near flowerbeds to provide additional habitat for a range of arthropods including spiders, centipedes and ground beetles.
- Check local invasive weed lists before planting any species that may be problematic. For example, some plant species may be recommended as an insectarium species overseas, but should not be planted if they are a potential declared or environmental weed species in South Australia.

For more information go to http://www.backyards4wildlife.com.au/uploads/FINAL2011_Weeds_web.pdf or http://www.pir.sa.gov.au/__data/assets/pdf_file/0005/136895/Declared_plants_of_SA_brochure.pdf

Do not plant invasive species or those listed on local noxious weed lists!

4.2. Some possible disadvantages of alternative plantings near vineyards

While there are many benefits of establishing insectariums in and around vineyards, there may also be some downsides created from planting insectariums, or other related plantings.

Possible negative impacts include:

- Insectariums harbouring pest species (such as LBAM, Vine Moth, Vine Weevil etc), broad leaved weeds such as cape weed can provide a host for overwintering LBAM, and other broad leafed species may also attract LBAM to the vineyard,
- Insectarium species may attract pests, potentially increasing their populations in the vineyard.
  - For example, a higher incidence of Vine Moths may be experienced near forest plantings and long grass may promote higher populations of vine weevils reaching the vine canopy.
- Beneficials such as ladybird beetles and spiders may prefer the comfort of the insectarium rather than in the vineyard.
  - This is one reason to consider how appropriate plant species can be incorporated in the vineyard, or how corridors of satellite plantings can be incorporated.
- Vegetation planted too close to the vineyard can shade vines and compete for water and nutrients; this can have a negative effect on the growth and development of vines.
- Seedbed preparation may create a temporary erosion risk. Ensure your timing is well planned.
- There may be an increased frost risk if cover crop or undervine species are not managed properly, and
- There may be a greater frequency of sapling growth in the vineyard from species such as red gums or other species located near the vineyard.

Figure 12: Beware of species which readily recruit saplings in vineyards.

4.3. Nurseries and support agencies

Government owned nurseries such as State Flora, Department of Water, Land and Biodiversity Conservation, **Belair Nursery** and **Murray Bridge Nursery** grow and sell indigenous plants of South Australia. References are available to show the species that are indigenous to the different areas of the State. A range of local nurseries may be able to provide suitable plants for your insectarium.

4.4. Books on native plants local to SA

There are an abundance of books that can be used to select appropriate species to plant in and around a vineyard property. Some of these resources are presented below.

Enhancing biodiversity in the vineyard

When making decisions about what plant species to plant and different planting options, you may wish to refer to the information developed in the 'Enhancing Biodiversity in the Vineyard' workshop notes presented to winegrowers in McLaren Vale and the Barossa (mentioned in ***Section 2***).

Additionally, there are many sources of information and expertise about selecting and maintaining plant species. For more information about websites, go to the 'Key References' section of these notes.

Books with information specific to South Australian native plants

To source a list of pre-European species local to your area go to Nature Maps (discussed in ***Section 3.3***) http://www.backyards4wildlife.com.au/index.php?page=nature-map-instruction and follow the directions provided on the website.

Other useful references include:

Bagust, P and Tout-Smith, L (2010) ***The Native Plants of Adelaide - Returning the vanishing natural heritage of the Adelaide Plains to your Garden***, SA Urban Forest Biodiversity Program, Department of Environment.

Bonney, N (1995). ***What seed is that? A field guide to the identification, collection and germination of native seed in South Australia***. Finsbury Press, Adelaide.

Costermans, L. (1981) ***Native Trees and Shrubs of South-eastern Australia.*** Rigby Publishers Ltd, Adelaide.

Dashorst, G and Jessop, J (2006) ***Plants of the Adelaide Plains and Hills.*** Board of the Botanic Gardens of Adelaide and State Herbarium, Adelaide.

Gibbs, J., and Gibbs, R. (2001) ***Grass Identification Manual – for everyone***. Native Grass Resources Group Inc, South Australia,

Jessup, J., (2006) ***Grasses of South Australia - an illustrated guide to the native and naturalised species***, Wakefield Press, Adelaide.

Mitchell, M. (2002) ***Native Grasses – An identification handbook for temperate Australia***. CSIRO, Collingwood. Third edition.

Prescott, A (1995) ***It's Blue With Five Petals - Wildflowers of the Adelaide Region***, Ann Prescott and Associates Pty Ltd, South Australia.

Woolcock, L. (1995) ***Wildflowers of the Mount Lofty Ranges - Fleurieu Peninsula to Barossa Valley***. Wakefield Press, Adelaide.

5. ENCOURAGING 'ECOSYSTEM SERVICES' THROUGH IPM

5.1. Background

Humans benefit from a multitude of resources and processes that are supplied by natural ecosystems. These include the maintenance of soil health, nutrient cycling, pollination, water filtration, waste absorption and breakdown. Collectively, these benefits are known as ecosystem services.

Ecosystem services are the benefits gained, either directly or indirectly, from the sum total of functioning ecosystems (either natural or modified).

We are specifically interested in the types of ecosystem services that relate to insect interactions in and around vineyards, insect pest control provided by beneficials and the provision of food and shelter to beneficials. By understanding the types of arthropods present within a vineyard we can ensure we do not to threaten the beneficials available to us.

There are potentially thousands of free little workers helping to control pest and diseases within the vineyard.

To maximise the use of biological control, chemicals must play a supportive rather than disruptive role. An understanding of the role ecosystem services play involves having a greater understanding of the interactions between beneficials, pest species and the environment.

Habitat enhancement includes the increased availability of areas to lay eggs and overwintering sites. The provision of alternative food can be important during periods when most common prey is not present (ie between generations or in the dormant season). Alternate food can be other prey species or food for adult predators or parasitoids (ie pollen, nectar or honeydew).

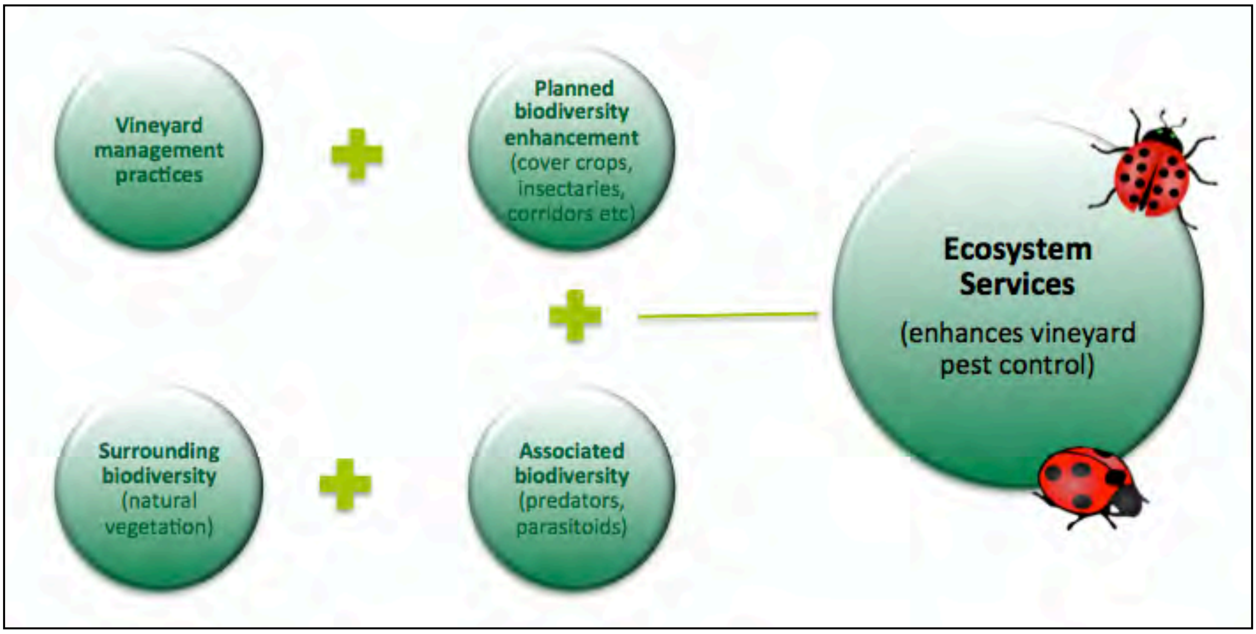

Figure 13: The roles of different types of biodiversity and their role in pest regulation.

Predators

Predators are typically larger than their prey. They require access to more than one prey individual during their development, whereas parasitoids develop on a single host. Predators commonly feed on prey as both larvae and adults. For example, Green Lacewing adults feed on pollen, nectar and honeydew, while the larvae feed on a range of pest insects including thrips, mites, moth eggs and small larvae and mealy bugs.

Parasitoids

Most parasitoids of vineyard pests are small wasps or flies. Female parasitoids lay eggs near, on or inside their hosts. Parasitoid larvae develop by feeding on larvae inside or attached to the outside of their hosts.

Many hosts are killed when adult parasitoids lay eggs on new hosts, or they host feed. Unlike generalist predators, most of the parasitoids found in vineyards are relatively specific in their selection of a host.

For example, the parasitic wasp *Trichogramma carverae* will only parasitise the flat egg masses of Light Brown Apple Moth and will not attack other vineyard pests. However, most generalist predators will attack a range of pest species including caterpillar larvae and mealybugs.

Unlike predators, parasitoids develop from the egg to adult stage on a single host.

5.2. Integrated pest management (IPM) principles

Pest control has been traditionally provided by a combination of natural enemies and/or chemicals. An Integrated Pest Management (IPM) strategy will focus on reducing pesticide use by employing a variety of pest control options to actively manage pests, below their economic or threshold injury level. It is unlikely a single approach will provide adequate control of vineyard pests.

Pest management can be achieved by using a combination of integrated control options such as:

- **Variety selection** (selecting grapevine varieties which have canopy or bunch architecture and which are less susceptible to harbouring or attack from certain pests and/or diseases),
- **Cultural control** practices such as canopy or soil management are used to reduce the susceptibility of grapevines to attack,
- **Biological control** measures, including augmented mass release of beneficials, parasitoids or other pest pathogens like *Bacillus thuringiensis* (Bt) are utilised to help control pest species, and/or
- **Chemical control** is used sparingly as a last resort, or carefully in conjunction with the other pest control options available.

The aim is to maximise the use of biological and cultural control options while minimising the use of chemicals or using chemicals in a supporting role only so their disruption to the natural balance of the system and beneficial organisms is minimised.

Where chemicals are sprayed, beneficial friendly or soft chemicals should be applied that are selective rather than broad spectrum (non-target specific).

By understanding the interactions between pest and beneficial species in the vineyard the viticulturist can work smarter, rather than harder, to create a system where minimal intervention is required.

A number of key pest species occur which can cause economic damage to vineyards. One of the most prevalent pest species is LBAM, a native leaf roller to Australia. Less frequently, depending on distribution or seasonal conditions are Vine Moth caterpillars, mealy bugs, vine scale, weevils, cutworm larvae and wingless grasshoppers. Conversely, there are a number of beneficials, which have the capacity to make a significant contribution to combating pest species in the vineyard. These will be discussed in more detail in ***Section 7***.

Integrating IPM principles with the development of insectaries[14]

To maximise the benefits of integrating IPM principles along with the development of insectariums, the following elements are needed for success:

- Correct identification of the pests to be managed,
- Understanding the risk posed to the grapevines from particular pests and using action thresholds for timely decision making,
- Sourcing accurate information about the life cycle and control options available to control the pests,
- Development and implementation of a regular monitoring program to observe pest (and beneficials) activity,
- Using weather forecasting to understand the impact weather conditions will have on the prevalence or the life cycle of the pest (ie degree days to monitor the time between LBAM moth flight and egg hatch),
- Using cultural practices to enhance control where possible (canopy management, removal of broad leaved weeds etc),
- Ensuring any sprays (biological, chemical or other) are applied effectively to the target. Use chemicals 'soft' on beneficials if possible (see the research on low toxicity ratings to beneficials in ***Section 5.5***)
- Utilising beneficials from insectariums where possible,
- Releasing mass reared beneficials to target key pests if required,
- Maintaining accurate records and documentation regarding your observations and actions,
- Assessing the impact of pest damage in the vineyard and on final fruit quality,
- Ongoing education and training is needed to fine tune your approach and respond to the different conditions experienced in different seasons.

Getting to know the enemy

It is important to thoroughly acquaint yourself with the vineyard pest you would like to control. Think about how an IPM strategy, including beneficials from an insectarium can be used to control the pest.

You will need answers to the following questions:

- What are the pest(s) food and habitat requirements?
- What factors influence its abundance?
- When does it enter the vineyard and where from?
- What attracts it to grape vines?
- How does it develop in/on the grapevine and when does it become economically damaging?

[14] Five features of IPM figure is downloaded from http://www.rinconvitova.com/CATALOG%202009%20screen.pdf

- What are its most important predators, parasites and pathogens?
- What are the primary needs of the beneficial organisms that can be used to combat the pest?
- Where do these beneficials overwinter, when do they appear in the vineyard, where do they come from, what attracts them to grapevines, how do they develop on the grapevine and what keeps them in the vineyard?
- When do the beneficials' critical resources (nectar, pollen, alternative hosts and prey) appear in the vineyard and how long are they available?
- Are alternative food sources accessible nearby and at the right times?

5.3. Monitoring strategies

When and where to monitor

While most monitoring activities are undertaken during the growing season, the winter months can also provide an opportunity to identify and monitor for a number of pests.

Monitoring in the vineyard can be focused on particular pests, based on an understanding of their lifecycles, previous history of pest occurrence in the vineyard and the stages of vine development most susceptible to damage.

For example:

- Examine buds early in the growing season for signs of bud mite damage (target unburst buds on healthy canes) from budburst and up to the end of October,
- The presence and severity of grapevine rust mite infestations can be determined using a Spring migration trapping technique in blocks where significant leaf bronzing occurred during the previous Autumn, and where stunted shoot growth (and leaves with crinkly margins) occurred in the previous Spring. However, this can be time consuming and requires specialist knowledge of mites for correct identification of species.
- Early season monitoring for LBAM larvae may focus on shoot tips, whereas from flowering onwards, lower leaves, the flower cluster and developing bunches may become the focus of your monitoring efforts.

Widespread monitoring of the vineyard over a number of seasons should enable specific strategies to be developed focusing on high-pressure areas or 'hot-spots'.

However, indicator blocks can also be identified using information about a pest's lifecycle, susceptible vine varieties and conditions for infection and spread.

Monitoring methodologies

Direct counts

You may wish to count all pests (and/or beneficials) in a set sample size. This allows you to determine the population size based on the number of pests per sample unit. For example the number of LBAM egg masses or caterpillars on 100 shoots randomly selected in a particular management unit.

Trapping

Trapping commonly employs interception methods such as the use of yellow sticky traps or pitfall traps. Traps are collected every one to two weeks and their contents analysed.

Random versus datum point sampling

Sampling can be either random (scattered around the vineyard), or by using datum points (sample points laid out at regular intervals). Pest monitoring is usually carried out on a random basis unless parts of the vine (cordon, shoots, leaf) have been tagged for follow up monitoring (LABM egg hatch). Traps are often set out on a grid and remain in the same position (datum points) throughout the season.

IPM monitoring methods for arthropods (Bernard 2007)[15]

IPM monitoring methods (suitable for commercial monitoring) of pests, beneficial insects, and spiders in the vine canopy include:

- **Weekly monitoring of whole vine shoots by direct observation:** randomly select and examine 100 shoots, scan shoots from tips to base, both sides of leaves, and a 10cm cordon section below each shoot. This method works well for monitoring pests (LBAM and vine moth larvae and eggs), and key beneficials (Green Lacewing activity is best sampled by egg counts).
- The strength of monitoring is in the ability to compare results week-to-week and season-to-season, and provide a fast response to infestations (within the time it takes LBAM eggs and mealybugs to develop into early instars).
  - Fortnightly monitoring of vine canopy is usually not recommended, as it results in a delay of up to 3-weeks in response to infestations.
- Where alternate row mowing is practiced, growers can **check beneficials in long grass mid-rows by suction sampling:** randomly chosen $1m^2$ units of long grass (for ≥ 60 sec), using a reverse vacuum suction leaf-blower every two weeks (it may be possible for winegrowers to use a hand held 'dust buster' for small sample plots).
  - The suction tube is fitted with a nylon bag to collect the catch. Catch is examined in a large white tray, and immobilised with a fine spray of water.

Setting realistic expectations

Your approach to monitoring arthropods in the vineyard needs to be based on realistic expectations:

- Your confidence in identifying arthropods, and
- How often you can get into the vineyard.

You approach needs to be effective in terms of making correct observations at key times so you have timely information to make informed decisions.

How do I get started?

You approach needs to be effective in terms of making correct observations:

- **What** – You will need to know what arthropods you are looking for (egg, larvae and/or adult stage),
- **Where** – You will need to know where to look (in sheltered areas of the canopy, under the bark, on the tips of new growing shoots, on leaf blades etc),
- **When** – It is important to know when to target your monitoring (growth stage) and how often you should be monitoring key arthropods activity in the vineyard, and
- **Why –** What information are you going to collect and what will you do with this information once you have it?

You will need to decide if you will manage the monitoring and decision making process by yourself, or use a pest scout and/or a consultant to ensure you get the outcomes you are looking for.

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[15] Bernard, M et al (2007) ***Guidelines for environmentally sustainable winegrape production in Australia: IPM adoption self-assessment for growers***. The Australian and New Zealand Grapegrower and Winemaker, March.

Figure 14: Take the time to observe what is going on in your insectarium.

The importance of monitoring arthropods interactions

By gaining an insight into the arthropod interactions that are occurring in your vineyard, will arm you with the necessary information and confidence to incorporate IPM principles including cultural, control options, beneficial insects and/or use a targeted spray program and/or 'soft' control options (ie chemicals which have a low toxicity rating to beneficial organisms, pheromone, mating disruptors or other biological control options such as Bt sprays).

Routine spraying without checking the arthropods activity (both pest and beneficial species) may prove to be more damaging to your pest control strategy, if you knock out natural beneficials and allow pest species to dominate.

This has been demonstrated in the past with a range of vineyard specific pests such as mites, LBAM, mealybugs, vine scale etc where broad-spectrum insecticides have been excessively sprayed. It is likely routine spraying will take more time, effort and involve the use of more toxic chemicals and potentially produce poor results in the long term.

By effectively monitoring the population dynamics of pest and beneficial arthropod species in and around the vineyard, it is possible to keep the damage to grapevines below economic thresholds by implementing IPM principles.

Monitoring within the vineyard is the only way to understand these processes properly, and act in a timely manner. This also allows for the incorporation of beneficial insects into your pest control program by releasing mass reared beneficials and/or maintaining a food and shelter source via an insectarium close by to sustain beneficial populations.

The aim is to provide food (nectar and pollen) preferably between September to April, and shelter to coincide with the peak times beneficials are needed in the vineyard.

It may be possible to overlap a number of flowering species to provide a food source throughout the season, or to flower at a key vine phonological stage (the time leading up to and at flowering), for example to encourage beneficials to keep LBAM larvae numbers in check.

Record keeping

There are many examples of pest monitoring record sheets available (some examples are presented in ***Section 8.8***); to provide an accurate record of your observations they should include information about:

- The location of the pest and its distribution,
- The stage of pest development (eg eggs, larvae, adult, pupae),
- The presence of beneficials,
- The stage of vine development,
- Weather conditions, and
- Any other observations relevant to vine health, disorders, observations.

It is important to take a consistent approach to monitoring so your results are standardised.

5.4. When to target monitoring for beneficials?

Beneficial species abundance varies over the growing season. For example, both generalist predators and specialist parasitoids provide a complex range of interactions for controlling LBAM.

The abundance of each beneficial will vary during the growing season, with each species contributing to a greater or lesser degree of control depending on the time they are present and the stage of the LBAM life cycle present in the vineyard, as outlined in Figure 15.

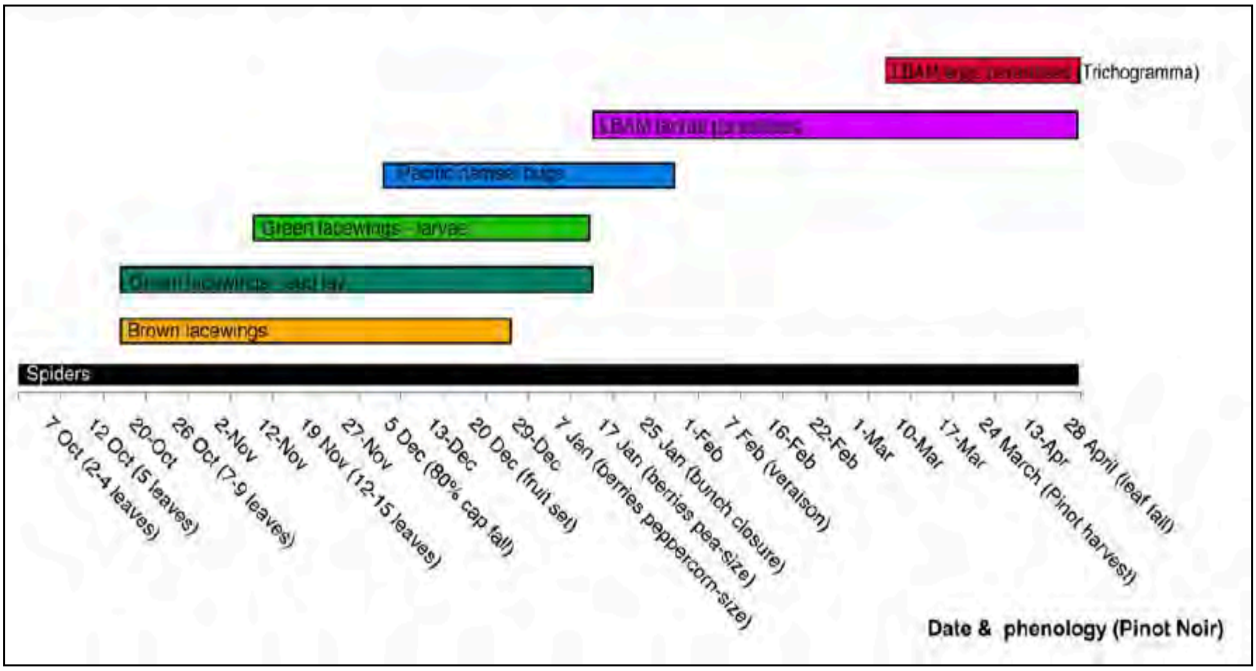


Figure 15: Approximate periods of high abundance of beneficials (Bernard 2007)[16].

[16] Bernard, M (2007) **Total system approach to sustainable pest and weed management in grapevines: Research and demonstration project.** Final report to Grape and Wine Research and Development Corporation, Adelaide.

5.5. The impact of spraying chemicals in the vineyard on beneficials

When considering the natural balance of a system it is important to understand the impact that a chemical application such as a fungicide, insecticide or weedicide may have on beneficial populations in the vineyard. Recent research has sought to understand the side effects of pesticides.

Centre for Environmental Stress and Adaptation (CESAR)

The **Centre for Environmental Stress and Adaptation** (CESAR) website contains images of beneficial arthropod groups, as well as information on 'Collateral Management for grapes in Australian vineyards'. For more information go to http://cesar.org.au/ and select 'Collateral Manage for grapes in Australian Vineyards'.

A simple chemical rating has been developed to provide an effective tool for growers to broadly assess the likely impact of their spray programs on beneficials.

Understanding the impact pesticides can have on beneficials allows winegrowers to make the right decisions regarding pest control options in the vineyard.

This index was validated across regions and some of the key chemicals contributing to low ratings have been identified[17].

Select a beneficial group below

Ladybird Beetle

Chemical	Beneficial Group	Toxicity	Reference (click for more details)
azoxystrobin	ladybird beetle - Cycloneda sanguinea	Harmless	Michaud, J. P. (2001)
azoxystrobin	ladybird beetle - Harmonia axyridis	Harmless	Michaud, J. P. (2001)

It is important to note that because a pesticide is safe for one parasitoid/predator, this does not mean that it is safe to all parasitoids/predators in all circumstances. For example, the addition of an adjuvant may render a 'safe' pesticide highly toxic. If in doubt, use as a spot treatment only and observe the effects carefully for at least two weeks[18].

If you wish to use chemicals in the vineyard and would like to assess the risk posed by spraying particular chemicals, check with your supplier of biological control agents on their potential impact, or for more information about pesticide toxicities for a range of beneficials go to the CESAR website http://cesar.org.au/index.php?option=com_collateral_manage.

IPM workshops

If you are interested in learning more about IPM you may wish to attend a workshop focusing on **'Integrated Pest Management for changing viticultural environments'**, which is run by the Australian Wine Research Institute.

These workshops give grape growers the ability to recognise and respond to pest threats in a timely and sustainable manner.

For more information, or to express an interest in having Research to Practice workshops in your region, please contact Marcel Essling via e-mail (rtp@awri.com.au), or telephone (08) 8303 6600.

[17] Thomson, L., Hoffmann, A. (2009) ***Sustainable viticulture 2010 and beyond: Vineyard management to maximize beneficial arthropods to increase the bottom line***. Final Report to the GWRDC. Project Number: MU 06/01, http://www.gwrdc.com.au/webdata/resources/project/MU_06-01.pdf

[18] http://www.biologicalservices.com.au/insecticide-compatibility.html

6. IDENTIFICATION AND MANAGEMENT OF KEY VINEYARD PESTS

6.1. Key pest arthropods found in vineyards

A quick reference guide to some commonly found pest species in vineyards is presented below (this is list not exhaustive but provides examples from the major family groups).

Table 8: The scientific classification of some common vineyard pests.

Predators					
Phylum	**Order**	**Family**	**Genus and species**	**Common Name**	**Picture**
Arthropoda	Lepidoptera (**Moths**)	Tortricidae	*Epiphyas postvittana*	Light Brown Apple Moth	
		Noctuidae	*Phalaenoides glycinae*	Grapevine Moth	
	Hemiptera (**Bugs**)	Pseudococcidae	*Pseudococcus longispinus*	Long-tailed Mealybug	
		Coccidae	*Parthenolecanium persicae*	Grapevine Scale	
	Acarina (**Mites**)	Eriophyidae	*Calepitrimerus vitis*	Grape Rust Mite	
			Colomerus vitis	Grapeleaf Blister Mite	
	Coleoptera (**Beetles**)	Curculionidae	*Phlyctinus callosus*	Garden Weevil	
		Scarabaeidae	*Heteronychus arator*	African black beetle	

Control options for common vineyard pests

Natural enemies of LBAM, Grapevine Moth, Mealybugs, Grapevine Scale, weevils, African Black Beetle and pest mites are thought to benefit from the provision of food and shelter resources provided in and around vineyards.

Beneficials include parasitoids, lacewings, predatory mites, predatory bugs and spiders. Some of these interactions and specific information regarding monitoring and IPM control measures have been published recently. The information presented below in Tables 9 to 16 has been paraphrased from (Bernard et al 2007)[19]. A copy of the entire article is presented for your reference in ***Appendix 2.***

Table 9: Control options for the LBAM (Bernard et al 2007).

Text in black IPM = compatible; text in blue IPM = transition; text in red IPM = incompatible

Light Brown Apple Moth (LBAM) *Epiphyas postvittana*				
Monitoring	**Bio-control (naturally present)**	**Cultural control (ecological engineering)**	**Bio-control (for release)**	**Chemical control**
Weekly monitoring of larvae, scanning 100 shoot-replicates from tip to base, is used to decide wheather to spray. Egg masses are also scored, but are not the main target, because the highest mortality occurs at egg-stage and 1st instar larva and egg-mass counts seldom correspond to larvae in the vine canopy. Delta traps may be used to indicate adult flights, but not to decide when to spray, as peaks in male numbers in traps do not correspond to peaks in larvae, or damage at harvest. **Infrequent (≤ fortnightly) monitoring;** quick checks only; monitoring of LBAM egg-masses only. **Monitoring LBAM by delta traps and pheromone lures; using male counts to decide when to spray.** This results in unnecessary insecticide use, as male trap counts can be very high (esp. early in the season), even though canopy larval infestations are negligible. These unnecessary early season sprays can damage beneficials, found in high numbers at this time.	Parasitoids of LBAM were extensively evaluated in Australia (Limestone Coast) recently by University of Adelaide and in a smaller study by the authors (Yarra Valley). The most common parasitoid to date is *Dolichogenidea tasmanica*, but many species make up the beneficial complex of LBAM, including parasitoids of larvae, and parasitoids of eggs *(Trichogramma sp).* Generalist predators also feed on LBAM.	Weed-free grass swards reduce LBAM host plants. Alternate row mowing allows grass to flower in every 2nd row to provide pollen food source, shelter from heat and low humidity for beneficials. Flowering buckwheat strips (1 in every 10 rows) provide high quality nectar for parasitoids, and for predators whose adult life stages feed on nectar and pollen (studied on *Dolichogenidea tasmanica*) at Lincoln Uni, New Zealand, and reduced LBAM damage below economic thresholds in some New Zealand vineyards, without a need to spray. Other nectar resource plants evaluated on LBAM parasitoids are: Phacelia (*P. tanacetifolia*), and white alyssum (*Lobularia maritima*).	*Trichogramma carverae*. Release only if naturally present bio-control enhanced by nectar resources is not able to achieve control.	Tebufenozide (e.g. Mimic 700 WP), and BT (*Bacillus thuringiensis*) formulations (e.g. Dipel DF) are used based on monitoring, in preference to other insecticides. Spray diary minimises use of sprays toxic to beneficials. Indoxacarb (e.g. Avatar®), emamectin (e.g. Proclaim®), spinosad (e.g. Entrust Naturalyte®) may be used within an IPM strategy. But each kills some beneficial species, and so the decision on which to use and when is based on monitoring of beneficial species and numbers (i.e.,spinosad is quite safe to many predatory species, but is harmful to parasitoid wasps, causing direct mortality and sub-lethal, effects such as reduced longevity and egg-lay; indoxacarb is toxic to both a key, predator, the green lacewing (*Mallada signatus*),and a key LBAM parasitoid (*Dolichogenidea tasmanica*) . These insecticides are thus used only when high pest numbers are present outside the tebufenozide spray window. Calendar-based use of any of the above, insecticides regardless of pest and beneficial numbers. Use of carbaryl (e.g., Carbaryl 500) or chlorpyrifos (e.g. Lorsban 500 EC) in place of any of the above insecticides.

[19] Bernard, M et al (2007) ***Guidelines for environmentally sustainable winegrape production in Australia: IPM adoption self assessment for growers***. The Australian and New Zealand Grapegrower and Winemaker, March.

Table 10: Control options for the Long-tailed Mealybug (Bernard et al 2007).

Long-tailed mealybug *Pseudococcus longispinus*

Alternative 1: Bio-control and minimal insecticide use

Mealybug outbreaks in wine grapes in Australia are only very recent (*c.* from 2000-01), yet the pest (Long-tailed mealybug) is considered native to Australia, and has been found in very low numbers in vineyards without causing economic damage for many years (controlled by beneficials). Mealybugs can be successfully controlled by:

(1) Relying on natural bio-control as far as is possible from early Spring into the season

(2) Controlling ant species that interfere with bio-control by an IPM-compatible method

(3) Monitoring mealybugs and beneficials throughout the growing season, and spraying only if required late in the season, when beneficial numbers decline.

Alternative II: Insecticides as the sole means of control

Outbreaks of longtailed mealybug (e.g. in WA vineyards) can have severe economic effects (direct damage, crop rejection due to sooty mould wine taint, and vine collapse due to vine leaf-roll virus transmitted by 1-2 instar longtailed mealybugs). As a result some growers and their advisers quickly reach for broad-spectrum insecticides; often from early in the season and for only minor infestations. Broad spectrum insecticides are also used as a butt-drench in WA, in an attempt to control weevils. In these ways, the best window of opportunity for bio-control (when mealybug numbers are low) is lost. Bio-control agents are killed by insecticides and growers become locked into repeated pesticide use. Mealybug numbers increase quickly in the absence of beneficials and several sprays may be used by capfall.

Even where mealybug control is achieved this way, it can be quickly lost soon after capfall, as no insecticides against mealybugs are registered for use in wine grapes after 80% capfall. Growers then face the dual problem of having **(a) no sprays available against mealybug, and (b) no natural bio-control left.**

As a result, mealybug numbers often soar during mid March and crops may be rejected. This in turn prompts pre-budburst, and early season applications of broad-spectrum insecticides the next Spring, and the pesticide treadmill is repeated. Ongoing insecticide use also increases the chances of exceeding MRLs. This scenario is completely environmentally and economically unsustainable.

Monitoring	Bio-control (naturally present)	Cultural control (ecological engineering)	Bio-control (for release)	Chemical control
Mealybug distribution is usually clustered unless large infestations occurred for several years. Monitor pest and beneficials. **Mealybug-specific methods** **(1)** Weekly checks of sheltered leaves at vine crowns on both sides of leaves, 4-5 leaves per vine crown, for 30 randomly chosen vines. **(2)** If mealybug is found, tag vines and check weekly to evaluate changes in pest numbers, development, and presence of beneficials (Many green lacewing eggs and larvae are found on mealybug-infested vines in IPM-vineyards). Use of pheromones is in development in the USA and New Zealand.	**Parasitoids** – many species are recorded from Australia. **Predators** noted feeding on mealybugs: green and brown lacewings (*Mallada signatus; Micromus tasmaniae*).	**Alternate row mowing** creates habitat for predators and parasitoids. **Flowering buckwheat, Phacelia** may also enhance parasitoids of mealybug and vine scale, and nectar feeding adult life stages of key predators e.g. *M. signatus*, by the same mechanisms that enhance LBAM parasitoids. But to date nectar evaluation on parasitoids of mealybugs or scale has not been done in Australia. Such research has a great potential to aid mealybug control and prevention.	**Green lacewing** *M. signatus*. The citrus mealybug predator *Cryptolaemus mountrouzieri* is available, but release results in vineyards to date have been variable and differed in regions, suggesting a possible preference for citrus.	**(1) Reliance on natural bio-control from early spring as far as possible, based on monitoring** (this is usually possible for the entire season under IPM, sometimes a spray may be needed) **(2) Targeted spot-baiting of honeydew-feeding ants (not all ant species!) that protect mealybugs from predation and parasitism, based on monitoring.** Baits, sticky bands, or baited spot chemical treatments are widely used by IPM specialists in many crops to improve bio-control. **(3) Buprofezin (e.g. Applaud®) timed to emergence of high crawler numbers; and if monitoring indicates spray is needed (beneficial numbers are low and unable to contain the pest).** This is best done based on expert long-term experience, in consultation with IPM specialists. **(4) Dormant winter oil spray** (e.g. Biopest) (based on monitoring and IPM specialist advice), if pest numbers were high late the previous season and beneficials did not achieve control. **Buprofezin (e.g. Applaud®) used on calendar basis. Broad-spectrum insecticides such as ethidathion** (e.g. Suprathion 400 EC) **and maldison** (e.g. Maldison 500), or other registered products timed to crawler emergence or on calendar basis, including as spot-sprays.

Table 11: Control options for Grapevine scale (Bernard et al 2007).

Grapevine scale ***Parthenolecanium persicae***				
Monitoring	**Bio-control (naturally present)**	**Cultural control (ecological engineering)**	**Bio-control (for release)**	**Chemical control**
Grapevine scale is relatively common, it occurs in clumps, difficult to detect at low densities. Infested vines usually have ants moving up the trunk, and scales are best detected by looking for ant activity. Leaves or bark on infested vines may glisten with honeydew, or be black with sooty mould. One generation occurs per year. Scales mature in Spring, becoming very convex, brown to reddish-brown, and are usually found near the bases of canes and under the bark of cordons. Cream eggs are deposited under adult females October - November. Crawlers (≤ 0.5mm) hatch *c.* early November. Crawler emergence can be monitored using double- sided sticky bands on canes above adult infestations. Clear to yellow crawlers (darkened with age) are found on underside of leaves in Summer, along leaf veins (inspect with 20 x magnification). They move from leaves to canes and older wood in Autumn, to overwinter. **Frosted scale.** New research indicates this species is more common in vineyards, than is generally assumed (Rakimov, unpublished data). Lifecycle and monitoring as per grapevine scale. Immature life stages are similar in appearance to grapevine scale. Eggs are white, and adults are covered in a white waxy powder. **Other species.** These are rare in vineyards, but can be common in other crops. Their biology has been worked out for other crops such as citrus and olives, but may vary in vineyards. Monitoring (as above).	Evaluation of the beneficial species complex is underway GWRDC Project DNR03/01. **Parasitoids.** Some six species of parasitoid wasps are recorded from *P. persicae* in Australia so far *Metaphycus maculipennis* and *Coccophagus lycimnia* appear to be the most important (Rakimov, unpublished data). **Predators.** Ladybird beetles, including *Cryptolaemus montrouzieri*, and caterpillars of a predatory moth *Mataeomera dubia* are important predators, but may not be naturally present in some regions. Larvae of the green lacewing (*Mallada signatus*) and brown lacewing (*Micromus tasmaniae*) feed on soft scale eggs and crawlers; both species are common throughout Australia. Other ladybird beetles also feed on scales, including *Rhizobius* sp. Predatory whirli-gig mite (*Anystis baccarum*; 1 -1.5 mm in size) abundant in Limestone Coast and King Valley vineyards and present elsewhere, was also noted to feed on eggs and crawlers.	Pruning can remove many scales from the vine, and minimal pruning can favour population increase. Pruning prior to dormant spray application helps increase spray coverage. Consider mulching cane prunings to kill scales which may otherwise move back onto vines. **Alternate row mowing** is a practice known to provide shelter and pollen for beneficials. **Provision of high quality nectar** for beneficials using buckwheat or phacelia is expected to also aid scale parasitoids, but research specific to these wasps has not yet been done. **Moderating nitrogen fertilizer and irrigation** if infestations are high, may reduce scale population growth.	**Green lacewing** *Mallada signatus* (as above) **Ladybirds:** *C. montrouzieri*; netting with nylon cloth over release spots for 2 weeks after release may improve bio-control, but this does not necessarily lead to establishment in vineyards.	**Enhancing naturally occurring biocontrol by minimal use of sprays toxic to beneficials. Spot-baiting (not broad-scale use of bait) of ant species that protect scales from natural enemies can improve biocontrol of scale.** Target only ants that tend scales and harvest honeydew, by applying minute amounts of bait mixed with insecticide to vines where ant tending is observed. No insecticides are registered as baits in grapes in Australia, and many ant species are beneficial, so baiting must be absolutely minimal and precisely targeted. Baits, sticky bands, barrier glue, or baited spot chemical treatments are widely use by IPM specialists in many crops to limit ant access to honeydew-producing pests and improve bio-control. **Spot-spraying clumped infestations with summer oil**, if beneficials and baiting alone did not achieve control, and scale numbers are high. Tag scale clusters and monitor crawler emergence to time sprays, targeting undersides of canes and cordons where most scales are found. Pruning prior to sprays can increase spray coverage. Summer oils are phytotoxic to vines, and care must be taken to avoid vine damage. **Spot-spraying infested vines with winter oil (e.g. Bioclear) at dormancy.** Winter oils are phytotoxic to vines and can only be used during full dormancy. **Spot-spraying broad-spectrum insecticides** such as methidathion Warning! S7 Poison (e.g. Suprathion 400 EC), maldison (e.g. Maldison 500) optimally timed to crawler emergence (based on monitoring) if beneficial numbers are low, can reduce crawler numbers. Tag scale clusters and monitor crawler emergence to time sprays. **Broad-scale use of the above insecticides** over whole vine block/s at crawler emergence, or on a calendar basis, or as dormant sprays. Broad-scale use of chlorpyrifos (e.g. Cyren 500 EC) or chlorpyrifos/ winter oil mixture in dormant vines. Only some chlorpyrifos products are registered for use in dormant vines and only against grapevine scale.

Table 12: Control options for Rust Mites (Bernard et al 2007).

Rust mite *Calepitrimerus vitis*				
Monitoring	**Bio-control (naturally present)**	**Cultural control (ecological engineering)**	**Bio-control (for release)**	**Chemical control**
To diagnose presence: Early spring rust mite damage is also called RSG due to rust mite in Australia, rust mite and bud mite are the only proven causal agents of RSG to date. Record spring damage when it is most pronounced: up to *c.*5-8 separated leaves. **Late summer damage:** Record severity of leaf bronzing (mid January to early March). If bronzing is moderate to severe spraying at woolly bud the next Spring will prevent RSG due to rust mite. If no/very low bronzing, there is no need to spray. This is reliable unless predatory mites were disrupted late in the season. **Species ID:** D. Knihinicki (DPI NSW-Yanco, or DPI Knoxfield).	**Predatory mites** (Acari: Phytoseiidae) Provide long-term preventative control of rust mite, bud mite, and other mite pests. Key species in Australian vineyards: *Typhlodromus dossei, T. doreenae, Euseius victoriensis, Galendromus occidentalis*, (Bernard, unpublished data) **Predatory thrips** *Haplothrips victoriensis* also feeds on rust mite and TSM.	**Alternate row mowing** provides grass pollen as a supplementary food source for predatory mites. **Nursery stock** hot water treatment of dormant cuttings (52°C for 60 min) eliminates rust and bud mites.	*E. victoriensis G. occidentalis* Only release where predatory mites at flowering are absent or very low. Assess naturally present numbers prior to release on ≥ 4 x 25 randomly collected leaves; by counting under microscope (6-12 x magnification), or scoring % leaves with predatory mites. OR Release without prior assessment if broad-spectrum pesticides were used in previous years.	**Minimise use of sprays toxic to predatory mites to achieve a lasting prevention of all pest mite outbreaks, without the need to spray each year. If a spray is needed against rust mite (i.e. leaf bronzing occurred the previous season), 'woolly bud spray' timed to rust mite migration from winter shelters is used.** Wettable sulphur (e.g. Thiovit Jet) is effective, IF spray volume saturates thick bark of vine cordons. Temperature ≥ 15 ºC during spraying improves wettable Sulphur action. **Annual 'woolly bud' spray** regardless of bronzing damage **Late season and post-harvest WS sprays** have little effect; over-wintering females are protected from late January **Lime sulphur at dormancy:** is highly toxic to most beneficials and can compromise IPM for the entire season.

Table 13: Control options for Bud Mites (Bernard et al 2007).

Bud mite *Colomerus vitis*				
Monitoring	**Bio-control (naturally present)**	**Cultural control (ecological engineering)**	**Bio-control (for release)**	**Chemical control**
To diagnose presence: **(i)** Locate clustered damage spots and tag. **(ii)** Collect healthy-looking un-burst buds soon after node-1 bud burst and up to mid-late October. Do not collect damaged buds with bleached, exposed hairs. These are long-dead, rotten inside and past the point when the cause can be diagnosed. **(iii) Species ID**: D. Knihinicki (DPI NSW-Yanco, DPI Knoxfield).	**Wettable sulphur spray (no oil!) immediately after node-1 bud-burst (at node-2 rosette, 1-2 wks after node-2 burst).** Diagnose bud mite prior to spraying and do not spray on routine annual basis. Spray volume to run-off, 0.5 L per vine is suggested. Reduced damage symptoms will not be evident until next Spring, because damage was caused before sprays were applied. 'Woolly bud' spray against rust mite does not work against bud mite, as bud mite (unlike rust mite) is protected deep inside buds at woolly bud. **Lime sulphur** (as above), and no effect on bud mite, which is deep inside winter buds.	**Alternate row mowing** provides grass pollen as a supplementary food source for predatory mites **Nursery stock** hot water treatment of dormant cuttings (52°C for 60 min) eliminates rust and bud mites.	*E. victoriensis* *G. occidentalis* Only release where predatory mites at flowering are absent or very low. Assess naturally present numbers prior to release on ≥ 4 x 25 randomly collected leaves; by counting under microscope (6-12 x magnification), or scoring % leaves with predatory mites. OR Release without prior assessment if broad-spectrum pesticides were used in previous years.	**Minimise use of sprays toxic to predatory mites to achieve a lasting prevention of all pest mite outbreaks, without the need to spray each year. If a spray is needed against rust mite (i.e. leaf bronzing occurred the previous season), 'woolly bud spray' timed to rust mite migration from winter shelters is used.** Wettable sulphur (e.g. Thiovit Jet) is effective, IF spray volume saturates thick bark of vine cordons. **Annual 'woolly bud' spray** regardless of bronzing damage **Late season and post-harvest WS sprays** have little effect; over-wintering females are protected from late January. **Lime sulphur at dormancy:** is highly toxic to most beneficials and can compromise IPM for the entire season.

Table 14: Control options for Weevils (Bernard et al 2007).

<table>
<tr><td colspan="2">Weevils causing damage in Australian vineyards:
(1) Garden weevil Phlyctinus callosus
(2) Black vine weevil Otiorhynchus sulcatus
(3) White fringed weevil Naupactus leucoloma
(4) Fuller's rose weevil Asynonychus cervinus
(5) Ecrizothis boviei native sp., no common name</td><td colspan="3">Wood-boring species
(6) Vine weevil Orthorhinus klugi
(7) Elephant weevil Orthorhinus cylindrirostis</td></tr>
<tr><th>Monitoring</th><th>Bio-control (naturally present)</th><th>Cultural control (ecological engineering)</th><th>Bio-control (for release)</th><th>Chemical control</th></tr>
<tr><td>Species (1-7): Bud damage, typical "shot hole" leaf feeding damage, and canopy defoliation in young and established vines can be very dramatic, but it is often localised to patches within a block. Berries can be damaged later in the season. Monitoring, also scout for adults and damage in the canopy. Wax-dipped corrugated cardboard bands (20 per block, placed around vine trunks, and checked weekly) are recommended (Agriculture WA).

Locate damage patches from early September, tag and inspect over the season to target spot sprays and cultural controls.

Obtain sp. ID to use specific cultural and bio- controls.

Species (1-5): Monitor also by exploratory soil digging in vine patches tagged the previous season.

Dig at regular time intervals from early Spring to monitor juvenile development into pupae, and to target mid-row cultivation to c. 70% pupae. This controls the part of the pest population found in the soil in vine mid-rows.</td><td>GWRDC Project RT04/17-4 is underway.

Ground dwelling predators can attack adults on emergence from soil, and on their walk to the vine canopy. They can be aided by habitat provision.</td><td>Species (1-5): To target juveniles; time mid-row cultivation to desiccate pupae. This method can be very effective in reducing the pest population, which is difficult to achieve by spraying alone, because immature stages are protected in the soil.

Soft vulnerable weevil pupae in the soil are exposed to drying. Optimal timing to 70% pupae. Actual time differs per each species, and can also differ site-to-site, and year-to-year.

Species (1-7): To target adults, habitat provision (undervine mulching, beetle banks, alternate row mowing) aid ground-dwelling predators such as staphylinid and carabid beetles, spiders, brown lacewing larvae, earwigs, etc.) to attack adult pests on emergence from soil.

Physical exclusion barriers (sp. 1-5): Barrier glue or grease bands placed around vine trunks can reduce the number of adults entering the vine canopy, and canopy damage. This need be combined with practices that reduce weevil populations. Large-scale use of barriers is labour-intensive, and may not be economical.

Host plant species (sp. 1-7): weevils feed on roots and foliage of many plants. Comprehensive identification of host plants and effects of eliminating these from mid-rows remain to be fully investigated.

Species (6): Removal, composting, or fine mulching of pruned canes.</td><td>To target juveniles of species (2): Nematode soil drench is available against sp. (2), suggested use is after cultivation see and consult the supplier, EcoGrow</td><td>Species (1-7): Target adults by spot spraying damage patches in early Spring when adults emerge; not broad-scale spray use, to minimise damage to biocontrol. Indoxacarb (e.g. Avatar®) is registered for use against garden weevil in Spring, alpha-cypermethrin (e.g. Crop Care Dominex Duo) against garden weevil in non-bearing vines. Both are toxic to beneficials, but indoxacarb is less toxic. Mealybug outbreaks can be induced by broad-spectrum sprays that kill natural beneficials.

This risk is far too great, and far outweighs any minor labour savings gained by not locating weevil patches.

Broad-scale canopy applications, or butt drenching of vine blocks with insecticides in early Spring, and on an annual basis.</td></tr>
</table>

Table 15: Control options for the African Black Beetle (Bernard et al 2007).

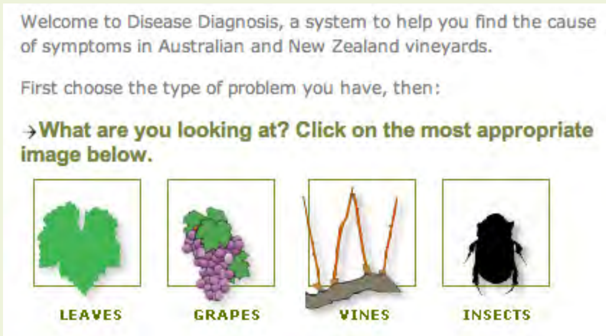
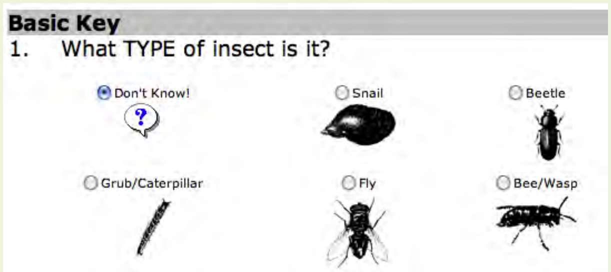
African black beetle *Heteronychus arator*				
Monitoring	**Bio-control (naturally present)**	**Cultural control (ecological engineering)**	**Bio-control (for release)**	**Chemical control**
Turf and pasture pest introduced to Australia from South Africa in the early 1900s. It is only a pest in vineyards during the first few years of vineyard establishment, owing to conversion from pasture. Tolerating such temporary damage is preferable, but may not always be realistic, due to instances of considerable damage in some regions in the first year of vineyard establishment (replanting, additional trellis training, and a delay in production). Thus at times a pre-planting treatment has been used. Pest numbers prior to planting and spraying can be evaluated with pitfall traps.	Some generalist ground dwelling predators may feed on this pest.	Cereal or canola crop rotations for up to two years prior to vine planting may be used to overcome these pest problems without the use of insecticides.	Nematode soil drench (EcoGrow, Australia) targeting young larvae, generally present in November, is effective. For precise application contact the supplier.	**Pre-planting broad-spectrum insecticide spray** is sometimes applied in an attempt to prevent damage during vineyard establishment. **Broad-spectrum insecticide use after planting** is often followed by severe rust mite outbreaks in the young plantings and associated drift-areas (M. Bernard, pers. comm.), due to suppression of predatory mites, which control rust mite. Where planting stock may have contained bud mite, risk of severe bud mite damage in the young vineyard is also increased. Damage to bio-control agents of other pests also occurs, and can lead to further pest outbreaks, outweighing initial control benefits gained by spraying for African black beetle.

Table 16: Control options for the European Earwig - if in plague numbers (Bernard et al 2007).

European earwig Forficula auricularia		
Monitoring	**Bio-control (naturally present)**	**Damage symptoms**
Scanning vines in first few weeks after bud burst, during routine monitoring for pests and beneficials. Traps of corrugated cardboard, or black plastic sleeves containing diet bait, can be placed around vine posts to monitor numbers, and are used in studies on this species. Accepting minor damage is part of an IPM strategy, especially since this species has now been identified as a key predator of LBAM larvae in vineyards at night. European earwigs can aestivate in hot Australian Summer conditions.	New research using video analysis of field predation shows this species to be a key, significant predator of LBAM larvae in the canopy, and on the vineyard floor at night. It was also noted to feed on LBAM in extensive LBAM studies, and on pest mites in Australia. It is recognised as an important generalist predator in European vineyards and orchards (of grape moth - *Eupoecilia ambiguella*, aphids, and psyllids). A superficially similar native predatory earwig (*Labidura truncata*) also occurs in Australia, and is present in vineyards	Localised damage (nibbled vine shoots) in early Spring has been attributed to European earwigs. But damage is difficult to separate from early Spring LBAM damage to buds and leaf rosettes, and so may be easily overestimated. The species causes no damage to vines later in the season.

There are many viticultural specific resources available which can assist you in identifying key vineyard insect species, including reference books and websites. For more information see:

Table 17: IPM publications and websites.

Publication	Picture
Nicholas, P.R., Magarey, P.A., Wachtel, M.F. (1994) **Diseases and pests. Grape Production Series No. 1**. Winetitles, Adelaide, South Australia. For more information go to www.winetitles.com.au or press here.	
Magarey, P et. al. (1999) **Field Guide for Diseases, Pests and Disorders of Grapes for Australia and New Zealand,** Winetitles, Adelaide. For more information go to www.winetitles.com.au or press here.	
Winetitles has an online disease diagnosis page, which allows the user to identify a range of diseases, pests and disorders of grapevines in Australia and New Zealand. For more information go to http://www.winetitles.com.au/diagnosis/index.asp	
PestWeb is a database that contains descriptions, lifecycles, damage and control for many insect pest species. For more information go to http://agspsrv34.agric.wa.gov.au/ento/pestweb/	

Alternatively there are pest and disease scouts who can assist you with vineyard monitoring and identification of both pest and beneficial species in the vineyard.

For more information, contact your regional grape growing association. A list of viticultural consultants can be found on the www.winebiz.com.au website. Go to the 'buyer's guide' and then to 'viticulture consultants', or press here.

7. IDENTIFICATION OF VINEYARD BENEFICIALS

7.1. Beneficial arthropods found in vineyards

Mass reared beneficials

Beneficial insects have many roles in the environment including pollinators, nutrient cyclers and natural enemies which can play an important part in suppressing populations of key pest species in vineyards.

There is a range of beneficials that can be found naturally occurring in vineyards. However, population levels may not be sufficient to adequately control pest species. The release of mass reared beneficials can boost the beneficial population numbers to outcompete key pest species if conditions are suitable.

It is important to understand the life cycle of each beneficial and only release them when conditions are optimal for their success. Be aware of the beneficial species likely to be encountered in the vineyard and to take into account their activity before deciding to spray chemicals in the vineyard. By understanding their shelter and food needs, insectariums can be planted to encourage natural populations in and around the vineyard. The following information is sourced from www.goodbugs.org.au.

Table 18: Examples of mass reared beneficials.

Beneficial species	Target pests	Description
Cryptolaemus (Native ladybird beetles) *Cryptolaemus montrouzeri* 	Mealybugs	A small lady beetle with an orange head, with black wing covers. Lays up to 500 eggs per female. Larvae and adults feed on mealybug eggs and nymphs.
	How to use	**Supplier**
	Cryptolaemus are sold as adults in small punnets each containing 40 beetles. Sprinkle adult beetles onto foliage near mealybug infestations.	Bugs for Bugs
Beneficial species	**Target pests**	**Description**
Damsel Bug *Nabis kinbergii* 	Aphids, moth eggs, small caterpillars.	Damsel Bugs are a fast moving general predator, which feeds on moth eggs and small larvae.
	How to use	**Supplier**
	Methods for using damsel bugs are currently being developed.	IPM Technologies
Beneficial species	**Target pests**	**Description**
Brown lacewing *Micromus tasmaniae* 	Brown lacewing larva and adults are a predator of a wide range of pests including aphids, moth eggs and small larvae.	Adults, 12 mm long with long lace like wings. Eggs, oblong, typically laid under leaves. Larvae have large pinchers for attacking prey (they do not carry debris on their backs like Green Lacewings do).
	How to use	**Supplier**
	Supplied as eggs from which larvae hatch shortly after arrival.	IPM Technologies

Beneficial species	Target pests	Description
Green lacewing *Mallada signatus* 	The green lacewing larva is a predator of a wide range of pests including thrips, mites, LBAM and vine moth eggs, and small larvae and mealy bugs.	Adults are 15 mm long with long lace like wings. Eggs are laid on fine stalks. Larvae, pinchers for attacking prey, carry debris on their backs.
	How to use	**Supplier**
	Lacewings are supplied as eggs from which larvae hatch shortly after arrival. Supplied either as loose eggs or with eggs adhered to small strips of paper.	Bugs for Bugs 
Beneficial species	**Target pests**	**Description**
Ladybirds **(various species)** 	Adults and larvae feed on a wide range of aphids and also feed on mites, thrips, small caterpillars, and moth eggs.	Labybird adults are small, round to oval and domed shaped with distinctive colourful markings. A female may lay from 200 to 1,000 eggs over two months.
	How to use	**Supplier**
	Hippodamia are sold as eggs on tape. Attach sections of the tape to plants where pests are present. Larvae will soon hatch and hunt down the pest species.	IPM Technologies
Beneficial species	**Target pests**	**Description**
Trichogramma wasp Trichogramma carverae 	Egg parasitoid of lightbrown apple moth, codling moth, oriental fruit moth and other species.	The tiny wasps lay their eggs into LBAM eggs. The wasp larva develops into a fully formed wasp inside the egg and emerges from a moth egg instead of a caterpillar.
	How to use	**Supplier**
	Sheets of capsules each yield 1,000+ wasps with 60 capsules per sheet. Place capsules in a grid fashion through the vines when LBAM are laying eggs.	Bugs for Bugs 
Beneficial species	**Target pests**	**Description**
Native predatory mite *Euseius victoriensis* 	Eriophyoid mites (Rust mites)	*Euseius victoriensis* is a naturally occurring mite species. It is teardrop-shaped and ranges in appearance from clear to honey-coloured. It moves quickly in a distinctive random searching pattern.
	How to use	**Supplier**
	Victoriensis are supplied on bean leaves. The leaves are placed into vines where target pests are present.	Bugs for Bugs

Other naturally occurring beneficials

There is a range of other 'good bugs' often found in vineyards where chemical spraying is minimised. They can be mass reared but most are not. They can be divided into two groups that are referred to as predators and parasitoids. The following information and photos are sourced from www.goodbugs.org.au. Additional pictures of beneficials will be added to the CESAR website in the future, for more information, see http://cesar.org.au/collateral-manage/beneficials-home.html

Predators

Predators such as lacewings, mites and ladybird beetles are often voracious feeders. They tend to feed on a number of natural prey species (and different life stages of pests) as well as supplementing their diet by feeding on alternative food sources, such as nectar and pollen. They do require a larger population of their prey to work effectively and may disappear once their food source has diminished.

Table 19: Examples of vineyard predators.

Predatory Beetles	**Target pests**
Ladybird beetles 	Adults are typically small, round to oval and domed shaped, with distinctive colourful markings. A female may lay from 200 to 1,000 eggs over two months. The eggs, spindle shaped are usually deposited in clusters. Larvae have three pairs of prominent legs and can be voracious feeders (pupae, larva and eggs). For more information about identifying ladybird beetles, go to http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_pests/ladybirds
Predatory Bugs	**Target pests**
Assassin bugs 	Assassin bugs can sometimes be found in vineyards. Their primary hosts are small to large larvae and they are capable of killing large caterpillars. They tend to be 12 to 18 mm long, with a curved beak, which is held beneath the narrow head. They have long front legs for grasping their prey.
Damsel bugs 	Adults are slender, about 8 mm long, pale brown, narrow head with large eyes and long antennae. They are a fast moving general predator, they move quickly when disturbed. Primary hosts are soft-bodied insects, moth eggs, small larvae aphids, mites, immature bugs and beetles.
Predatory shield bugs 	Two species of predatory shield bugs; *Oechalia schellenbergii* and *Cermatulus nasalis*, can often be seen feeding on slow-moving larval stages of moths, butterflies and beetles. Adults have horn like protrusions, shield shaped body with overlapping wing tips, extended mouthparts. They are voracious feeders and attack even large grubs.

Other predators	
Hover fly 	The adult hover fly with its black and yellow and black-banded abdomen is often seen hovering above plants. The adults feed on nectar and pollen. The female lays its white oval eggs amongst colonies of aphid or mites, on which the maggots feed. It has been suggested that hoverfly larvae may also eat LBAM caterpillars.
Lacewings (brown and green) 	There are many species of lacewing - green and brown lacewings are the most familiar to farmers and commonly occur in crops. The green lacewing *Mallada signata* lays its eggs in groups on fine stalks.
Spiders 	There are many species of spiders found in vineyards, and these are likely to vary from region to region and depending on the time of year. They can be roughly divided into three categories: • Soil dwelling (wolf spiders), • Foliage dwelling (jumping spiders, lynx spiders, night stalkers, flower spiders, crab spiders), and • Web spinners (orb weavers, tangle web spider). The ground and foliage dwellers are likely the most important spiders in caterpillar pest control. Spiders feed on LBAM and vine moth eggs, small to large caterpillars.
Ants 	Ants feed on moth eggs and small caterpillars. Ants can be a significant predator in drip-irrigated crops such as grapevines where patches of soil remain dry. Ants can contribute to pest control however they may disrupt the activity of other biocontrol agents and can protect mealy bugs so they can access their honeydew.

Parasitoids

Parasitoids such as tiny wasps deposit an egg into a pest, usually at a critical life stage. The larva that hatches ultimately consumes and kills the pest.

Each parasite completes its entire development on an individual pest. Parasitoids are mostly very host-specific and often will attack only one species of pest. They tend to be very good at finding them even when densities of the host are relatively low.

Table 20: Examples of vineyard parasitoids.

Parasitoids	
Trichogramma 	Trichogramma wasps are found in most crops, where there are moth pests and where spraying is minimised.
Cotesia wasps 	Cotesia wasps (4 mm long) are a parasitoid of caterpillar larva and produce characteristic yellow or white bundles of cocoons. A species of the parasitic wasp *Metaphycus* is being evaluated for commercial mass-rearing as a biological control agent of grapevine scale.
Dolichogenidea wasp 	The *Dolichogenidea* wasp is one of the most abundant parasitoids in vineyards and readily lives in habitat other than vineyards, including native vegetation.
Tachinid flies 	Tachinid flies are stout bodied and bristly and usually grey brown in colour. They range in size from 5 to 10mm in length. There are many species of Tachanid flies and their maggots have numerous hosts including caterpillars, bugs and beetles.

Some insect species such as European wasps, katydids (grasshoppers and crickets) and earwigs can be both a beneficial and a pest.

They feed on other insects for part of their life but can also chew grapevine leaves etc at other times. For example, earwigs can be veracious feeders of LBAM larvae, mites and a range of other insects, but can also feed on grapevine leaves and if they are in high enough numbers in the canopy, can cause issues if they are harvested along with the grapes.

A table of key vineyard pests and some of their commonly occurring natural enemies are presented below.

Table 21: Key vineyard pests and their common natural enemies

Pest	Natural enemies					
	Lace wings	Ladybird beetles	Parasitic flies	Parasitic wasps	Predatory mites	Other groups and examples
Light Brown Apple Moth	Lace wing larvae	Ladybird beetles	Parasitic flies	Parasitic wasps (*Dolichogenidea tasmanica*, *Trichogramma carverae*)		Birds *Bacillus thuringiensis* Predatory spiders Shield bugs Damsel bugs Assassin bugs Earwigs
Vine Moth	Lace wing larvae	Ladybird beetles	Parasitic flies	Parasitic wasps		Birds *Bacillus thuringiensis* Predatory spiders Shield bugs Damsel bugs Assassin bugs Earwigs
Mealybugs	Lace wing larvae	Ladybird beetles		Parasitic wasp, *Coccophagus gurney*		
Grapevine Scale	Lace wing larvae	Ladybird beetles		Parasitic wasps (*Metaphycus Maculipennis, Coccophagus lycimnia)*		Predatory moth (*Mataeomera dubia)* Predatory whirli-gig mite (*Anystis baccarum*)
Rust Mites	Lace wing larvae	Ladybird beetles			Predatory mites (*Typhlodromus dossei, T. doreenae, Euseius victoriensis, Galendromus occidentalis)*	*Predatory thrips* Damsel bugs Hover fly larvae
Thrips	Lace wing larvae				Predatory mites	Predatory thrips
Weevils	Lace wing larvae					Rove Beetles Ground Beetles Spiders Earwigs Nematodes (soil drench) Vertebrates Birds
Snails			Parasitic flies			Predaceous ground beetles Vertebrates Birds

It is always important to consider the numbers of beneficial insects before deciding on appropriate control strategies.

8. COLLECTING ARTHROPODS

8.1. Pheromone and port wine traps

Pheromone (delta) and port wine traps can be hung in the vineyard to indicate Light Brown Apple Moth activity.

Pheromone traps are commercially available and while they relatively expensive they have the benefit of being specific to LBAM. They contain a small rubber plug impregnated with a sex pheromone that attracts the male moth. Moths that enter the trap get caught on a sticky card and can be counted easily.

Port wine traps can be made from any suitable container about 15cm in diameter and at least 20cm deep, a PVC cylinder cut from a length of pipe with an end cap works well.

The container is partly filled with a 10% percent solution of cheap port wine. Cover the cylinder with wire mesh (1cm holes) to help non-target species such as birds from the trap. Port wine traps attract a wide range of insects, so growers using them need to be able to identify LBAM correctly. These traps should ideally be inspected twice a week. This allows freshly caught moths to be counted easily[20].

It is important to note that there is often a poor association between moth numbers and the subsequent population level of LBAM and Vine Moth on grapevines.

It is preferable that peaks in moth activity be used to schedule detailed monitoring of vines rather than proceeding with the application of sprays.

8.2. Yellow sticky traps

Yellow sticky traps are designed for monitoring canopy dwelling arthropods.

The special shade of yellow attracts a broad spectrum of flying insects (in the same way flowers do) including Hymenoptera (wasps), Thysanoptera (thrips), Hemiptera ('true' bugs with sucking mouthparts like leafhoppers, shield bugs, apids etc), Neuroptera (lacewings), Diptera (predatory flies), Hymenoptera (parasitoid wasps) and Coleoptera (ladybird beetles) in a vineyard.

Yellow sticky traps are useful for detecting the arrival of certain flying insects in the vineyard and to provide an indication of their activity. However they do not provide a complete picture of the populations dynamics and should not be relied on in isolation to other monitoring options, such as scouting in vine canopies.

For example adult insects may settle into vines after flying and juvenile (non flying stages) such as eggs and larvae) may survive spraying applications but may not show up on the traps[19].

[20] http://new.dpi.vic.gov.au/agriculture/farming-management/organic-farming/organic-viticulture/arthropods-pest-management

Using yellow sticky traps

Sticky traps should be checked and changed on a weekly or fortnightly basis (as required). Ideally they should be placed above the growing tips of vines early in the growing season (place on a permanent catch wire or raised foliage wire) to catch insects hovering above the vines, or below the cordon wire to avoid the traps from getting stuck (or lost) inside the vine canopy.

If you do not wish to maintain traps on a weekly basis, you may wish to put them out on the first day of each month during the early and late stages of the growing season (from October to April). The majority of catches are likely to occur in late November and December (this also coincides with grapevine flowering). The sampling strategy will depend on the data to be collected. **Once the populated sticky traps are collected, put them into a 'snap lock' bag for future identification and easy storage.**

Insect identification

You can inspect the insects caught on a yellow sticky trap with the naked eye to get an indication of the number and different types of insects present. For small insects you may need to use a hand lens or a microscope to accurately count and identify the species present. If you are unsure, you can get a professional to assess and 'score' populated traps for you.

Part of an integrated pest management (IPM) strategy

Remember, yellow sticky traps will not tell you the presence or absence of non-flying juvenile stages of key pests, the early stages or the extent of any damage. It is important to use yellow sticky traps in conjunction with regular monitoring to provide an overall picture of what is happening in the vineyard.

Comparing the activity of flying insects in and around the vineyard

Sticky traps can also be placed within the plant border habitat on the vineyard margin and in the vine canopy, starting from the insectarium (planted group of host species, hedgerow etc) at intervals of ten to twenty metres. This is a useful way to get an indication of what species are present and the change in population. This process could also be used to gauge the impact of any chemical application or the release of mass reared beneficials into the vineyard.

8.3. Transparent sticky traps

Some insects found in and around vineyards such as Lepidoptera (moths) and Neuroptera (lacewings), are most effectively trapped using transparent sticky traps. These traps can be constructed by installing a vertical screen of transparent plastic, such as transparent kitchen film stretched between two stakes and coated with pest glue such as 'Stickem special' which can be sourced from 'Bugs for Bugs' (www.bugsforbugs.com.au).

Additionally, you can inspect the spider webs of orb-weaving spiders that are particularly good at constructing spider webs between grapevines and across the mid-row of vineyards to capture prey.

8.4. Pitfall traps

Pitfall traps are designed for monitoring non-flying and ground dwelling arthropods including Hemiptera ('true' bugs), Neuroptera (lacewing larvae), Araneae (spiders), Hymenoptera (ants) and Coleoptera (beetles) in a vineyard.

Dry pitfall traps

These traps consist of suitable wide-mouthed containers sunk into the soil so their opening is flush with the ground surface. Containers, ranging from disposable plastic cups to ice cream containers or plastic buckets, are suitable.

Often a 'cup inside of a cup' is used so that the contents can be easily collected without disturbing the hole used for collection.

Wet pitfall traps

There is a range of liquids that can be used to kill the arthropods as they are trapped. Ethylene glycol (antifreeze) can be purchased readily, is commonly used to provide a 'quick kill' and help to preserve the specimens until they are collected.

Pitfall traps can be monitored for a particular pest species such as African Black Beetle (which is attracted to light), or a range of species (pest and beneficial) via opportunistic capture. An increase in the activity of adults may indicate the emergence of a new generation and the possibility of an increase in the risk of damage to vines (if a pest species is found).

To monitor ground dwelling insect activity, grape growers may wish to place one or more pit fall traps in a 'hot spot' where insect damage such as chewing to young vines has occurred.

To monitor insect activity in a particular management unit (variety, or block), it is recommended growers install either pitfall and/or yellow sticky traps at five sampling points, which can be monitored throughout the season.

Ethical use of pitfall traps

If you are using a wet pitfall trap with a preserving solution, it is important to consider the humane use of traps if there is likely to be a delay before drowning and preserving insect species caught. Outlines for the ethical use of pitfall traps can be found at www.animalethics.org.au or press here.

Alternatively, Queensland Department of Environment and Resource Management have developed a Standard Operating Procedure for using of pitfall traps and this article can be downloaded from the www.uq.eu.au website or press here.

8.5. Cardboard traps

Cardboard bands placed around the upper portion of vine trunks, or layers of hessian, newspaper etc placed at the base of vines, are attractive hiding places for adult weevils and earwigs that use these locations for shelter during the day. Their numbers can be checked easily by inspecting the traps or shaking the traps over a white tray or sheet to count their numbers.

8.6. Soil plugs

You may wish to assess the type and number of arthropods living in the soil. This can be done by digging a plug of soil using an auger or shovel in the top 15cm of soil (this is where most of the action is) and counting the number of mites, earwigs, slugs, earth worms, centipedes slaters etc that you find. This may be in response to the application of mulch or the change in vineyard practices (less cultivation or less chemical usage).

8.7. Monitoring the numbers of arthropods – insectarium versus vineyard

If you are interested in assessing the impact of an insectarium on the number and diversity of arthropods compared to arthropod activity in the vineyard, you may wish to set up some set data collection points (yellow sticky traps and pitfall traps) both in the insectarium vegetation and in the vineyard - twenty metres and fifty metres from the vineyard edge. It is a good idea to have five replicates at each location and take the mean of the five traps as an indication of activity.

8.8. Data collection sheets – examples

Examples of data collection sheets for a number of monitoring exercises are presented below.

EVALUATION OF INSECTARY PLANTINGS – MONITORING SHEET

Background information			
Monitor's Name		Date	
Type of configuration*		Time	
Insectary plant species		Weather conditions	
Approximate size of planting monitored		Pest management activities	
Distance from other insectary planting(s)/ habitat			

Pest or beneficial species	Pest or beneficial group**	Number of adults	Number of immature specimens	Feeding on flowers? (Y/N)	Sampling method***

* Insectarium, field border (hedgerow), cover crop.

** Choices for beneficial groups (ie Ladybird beetle, lacewing, parasitoid wasp, predaceous wasp, predacious bug etc).

*** Monitoring, pitfall, yellow sticky trap, net, suction vacuum.

COMPARING ARTHROPOD ACTIVITY IN DIFFERENT PARTS OF THE VINEYARD – MONITORING SHEET

This sheet is to be used for monitoring individual vineyard blocks, reference points or sections of particular interest ie vines near different cover crops or a specific distance from an insectary. This monitoring sheet can be used to keep a record of the status of key pest and beneficial species, and the health of insectary plants and/or vines in these locations (keep a track of them on a vineyard property map). It can also be used to compare locations for potential 'before and after' or 'near and far' effects of insectary plantings. This information can then be graphed or mapped.

Background information			
Monitor's Name		Date	
Block		Time	
Vine growth stage		Weather	
Approx size of area sampled		Pest management activities	

If insectary plants are present at or near the location being sampled enter the details here			
Type of configuration*		Date planted	
Approximate size of insectary planting		Distance from other insectary planting(s)	

Pest or beneficial species	Pest or beneficial group**	Number of adults	Number of immature specimens	Other signs of presence or damage?	Sampling method***

* Insectarium, field border (hedgerow), cover crop.
*** Choices for beneficial groups (ie Ladybird beetle, lacewing, parasitoid wasp, predaceous wasp, predacious bug etc).
**** Monitoring, pitfall, yellow sticky trap, net, suction vacuum.

INSECTARIUM COST/BENEFIT ASSESSMENT SHEET

This checklist is to be used for comparing the cost/benefit of insectary plant species, and types or configurations under consideration. You may not have the answers to all of the questions posed below, but by considering these factors you can help to ensure that an insectary planting will be useful. If information is not available in advance, it may be necessary to carry out some targeted on-site research and/or monitoring to get that information during the first seasons in which the insectary plantings are implemented.

Insectary plant	Plant 1	Plant 2
Name of insectary plant(s) to be evaluated		

Indicator		Plant 1			Plant 2		
		Observed outcome			Observed outcome		
		Positive	Neutral	Negative	Positive	Neutral	Negative
Organism	Does this plant and/or habitat type fulfil the requirements for nectar and pollen foods or other habitat for the beneficial of interest?						
	Does this plant type have an effect on these organisms on other parts of the vineyard?						
	Is this plant type more attractive to these organisms than other plants on the vineyard?						

Indicator		Observed outcome			Observed outcome		
		Positive	Neutral	Negative	Positive	Neutral	Negative
Timing	Do the insectary plantings provide sufficient floral resources for the organisms of interest at the right times and places in the system?						
	Does the insectary planting attract the natural enemy away from the target pest?						

Indicator		Observed outcome			Observed outcome		
		Positive	Neutral	Negative	Positive	Neutral	Negative
Agronomic	How competitive is the insectary planting with the crop, or does it harbour other weeds?						
	Is the insectary plant known to serve as an alternate host for crop diseases?						
	Is the insectary plant known to serve as an alternate host for crop pests?						

Indicator		Observed outcome			Observed outcome		
		Positive	Neutral	Negative	Positive	Neutral	Negative
Economic	Can the insectary plant be harvested and sold as a crop (or seed)?						
	What are the costs of seed, establishment and maintenance under specific conditions?						
	How do these costs and availability of insectary plantings compare to other management options?						
	If land is taken out of production with the planting type, what is the cost?						

GENERAL VINEYARD – MONITORING SHEET

Modified from a record sheet prepared by Martina Bernard as part of GWRDC project LTU 02/01 CESAR, LaTrobe Uni & IPM Technologies

This sheet is to be used for monitoring individual vineyard blocks, reference points or sections of particular interest ie vines near different cover crops or a specific distance from an insectary. This monitoring sheet can be used to keep a record of the status of key pest and beneficial species. It can also be used to compare locations for potential 'before and after' or 'near and far' effects of insectary plantings, this information can then be graphed or mapped.

Background information			
Monitor's Name		Date	
Block		Time	
Vine growth stage		Weather	
Approx size of area sampled		Pest management activities	

If insectary plants are present at or near the location being sampled enter the details here			
Type of configuration		Date planted	
Approximate size of insectary planting		Distance from other insectary planting(s)	

	Light Brown Apple Moth (LBAM)	Monitoring method	Number
PESTS	LBAM males	Average per yellow sticky trap	
	LBAM egg masses (fresh)	Average per 100 canes	
	LBAM egg masses (emerged)	Average per 100 canes	
	LBAM larvae (instar 1 to 2)	Average per 100 canes	
	LBAM larvae (instar 3 to 4)	Average per 100 canes	
	LBAM larvae (instar 5 to 6)	Average per 100 canes	
	LBAM larvae	Average per 100 bunches	
	Grapevine Moth		
	Larvae	Average per 100 canes	
	Mealybugs		
	Number of vines infested	4 crown leaves of 25 vines searched	
	Number of vines infested (ants present)	4 crown leaves of 25 vines searched	
	Number of mealybugs	Average per 100 leaves	
	Number of new infested vines compared to last week		

	Green lacewing (GLW) / Brown lacewing (BLW)	Monitoring method	Number
BENEFICIALS	GLW eggs	Average per 100 canes	
	GLW larvae	Average per 100 canes	
	BLW larvae	Average per 100 canes	
	BLW adults	Average per 100 canes	
	Spiders		
	Spiders (adult or spiderling)	Average per 100 canes	
	Parasitised LBAM		
	LBAM egg-masses (parasitized by *Trichogramma*)	Average per 100 canes	
	LBAM larval parasitoids - cocoons	Average per 100 canes	
	Ladybird beetles		
	Larvae	Average per 100 canes	
	Adult	Average per 100 canes	
	Rove beetles		
	Adults	Average per 100 canes	
	Damsel bugs		
	Adults	Average per 100 canes	
	Beneficial other		
		Average per 100 canes	
		Average per 100 canes	

8.9. Identifying monitoring results from the vineyard (or field)

The arthropods collected on yellow sticky traps can be identified while they are stuck on the card and pitfall trap contents can be deposited into a petri dish for identification by eye, or for small species use a stereo-microscope at a magnification of 6 to 40 times.

Sort the arthropods groups to the most obvious order and then attempt to identify the important, pest species, predators and parasitoids by Family if possible.

If you are unsure of the Family, other growers within your region may be able to help you to identify the arthropod. You may be able to compare your specimen with a reference collection, pictures within this booklet or request assistance from entomologists offering an identification service (this is best done on a regional basis as identification can be time consuming and costly).

Table 22: The scientific classification of some common vineyard predators.

Predators					
Phylum	**Order**	**Family**	**Genus and species**	**Common Name**	**Picture**
Arthropoda	Coleoptera (Beetles)	Coccinellidae (**Ladybird beetles**)	*Cryptolaemus montrouzeri*	Mealybug Ladybird	
			Coccinella transversalis	Transverse Ladybird	
			Hippodamia variegata	Spotted Amber Ladybird	
			Coccinella undecimpunctata	Eleven Spotted Ladybird	

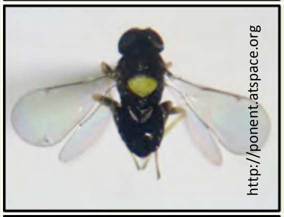
Predators - continued

Phylum	Order	Family	Genus and species	Common Name	Picture
Arthropoda	Coleoptera (Beetles)	Staphylinidae (**Rove Beetle**)		Staphylinid or Rove Beetle	
		Carabidae (**Ground Beetles**)			
	Lepidoptera	Noctuidae (**Predatory Moth**)	*Mataeomera dubia*	Scale-eating Caterpillar	
	Dermaptera (**Earwigs**)				
	Chilopoda (**Centipedes**)				
	Hymenoptera (**Ants**)				

Predators - continued					
Phylum	**Order**	**Family**	**Genus and species**	**Common Name**	**Picture**
Arthropoda		Pentatomoidea (**Shield Bugs**)	*Oechalia schellenbergii*	Spiny Predatory Shield Bug	
	Hemiptera (Bugs)		*Cermatulus nasalis*	Glossy Shield Bug	
		Nabidae (**Damsel Bugs**)	*Nabis kinbergii*	Pacific Damsel Bug	
		Reduviidae (**Assassin Bugs**)	*Pristhesancus plagipennis*	Assassin Bug	
	Neuroptera (Lacewings)	Chrysopidae (**Green Lacewings**)	*Mallada signatus*	Green Lacewing	
		Hemerobiidae (**Brown Lacewings**)	*Micromus tasmaniae*	Tasman's Lacewing	
	Thysanoptera (Thrips)	Aeolothripidae (**Predatory Thrips**)	*Aeolothrips fasciatus*	Banded Thrips	
		Phlaeothripaidae (**Predatory Thrips**)	*Haplothrips victoriensis*	Tubular Black Thrips	

Predators - continued					
Phylum	**Order**	**Family**	**Genus and species**	**Common Name**	**Picture**
Arthropoda	Araneae (**Spiders**)	Lycosidae	*Lycosa sp*	Wolf Spider	
		Araneidae	*Celaenia excavata*	Bird Dropping Spider	
			Eriophora biapicata	Garden orb Weaver Spider	
		Clubionidae	*Cheiracanthium spp.*	Nightstalking Spider	
	Acarina	Anystidae (**Predatory Mites**)	*Anystis baccarum*	Predatory whirli-gig Mite	
		Phytoseiidae (**Predatory Mites**)	*Euseius victoriensis*	Victorian Predatory Mite	
			Galendromus occidentalis	Western Predatory Mite	

Table 23: The scientific classification of some common vineyard parasitoids.

Parasitoids					
Phylum	**Order**	**Family**	**Genus and species**	**Common Name**	**Picture**
Arthropoda	Diptera (flies)	Syrphidae (**Hoverflies**)		Hoverfly	
		Tachinidae **(Tachinid Flies)**	*Voriella sp*	Tachinid Fly	
	Hymenoptera (Wasps)	Trichogrammatidae (**Trichogramma wasps**)	*Trichogramma carverae*	*Trichogramma wasp*	
		Braconidae (**Parasitoid wasps**)	*Dolichogenidea tasmanica*	*Dolichogenidea wasp*	
			Cotesia sp	Cotesia wasps	
		Encyrtidae (**Parasitoid wasps**)	*Metaphycus Maculipennis*	Metaphycus wasp	
		Aphelinidae (**Parasitoid wasps**)	*Coccophagus lycimnia*	Coccophagus wasp	
		Chalcidoidae (**Parasitoid wasps**)	*Brachymeria sp*	Brachymeria wasps	

9. WHO CAN HELP ME WITH THE IDENTIFICATION PROCESS?

9.1. Insect identification (entomology) experts

A range of insect identification specialists is available both within South Australia and interstate. A list of entomologists with expertise in identifying vineyard pest and beneficial insect species and/or their area of expertise/research are presented below.

Table 24: Entomologists with expertise in identifying vineyard pest species and beneficials.

Name	Title	Contact Details	Expertise / Recent Projects / Services
Based in South Australia			
Greg Baker	A/Leader	**SARDI** **T:** (08) 8303 9544 **E:** greg.baker@sa.gov.au **W:** www.sardi.sa.gov.au	Economic thresholds and sampling guidelines for lightbrown apple moth in grapevines.
Cate Paull	Research Officer	**SARDI** **E:** cate.paull@sa.gov.au	PhD thesis titled 'The ecology of key arthropods for the management of *Epiphyas postvittana* in Coonawarra vineyards, South Australia'.
Peter Crisp	Entomologist	**SARDI** **T:** (08) 8303 9371 **E:** peter.crisp@sa.gov.au	Research into the use of milk and whey as potential replacements for synthetic fungicides and sulfur in the control of powdery mildew.
Andrew Austin	Professor	**Adelaide University** **T:** (08) 8303 8240 **E:** andy.austin@adelaide.edu.au	The biology, systematics and molecular phylogenetics of parasitic wasps.
Mike Keller	Associate Dean	**Adelaide University** **T:** (08) 8303 7222 **E:** mike.keller@adelaide.edu.au **W:** www.adelaide.edu.au	Biological control; integrated pest management; insect behaviour; pest control. Two PhD students are currently researching the relationship between LBAM and parasitoids.
Based interstate			
Ary Hoffmann	Australian Laureate Fellow	**Melbourne University** Department of Zoology **T:** (03) 8344 2282 **E:** ary@unimelb.edu.au	Extensive research into vineyard beneficials, insectariums, arthropod trapping and identification techniques and related areas of study.
Linda Thomson	Senior Research Fellow (GWRDC)	**Melbourne University** CESAR - Zoology Department **T:** (03) 8344 2200 **E:** lthom@unimelb.edu.au	
Martina Bernard	Honorary (Fellow)	**Melbourne University** Department of Zoology **E:** martinab@unimelb.edu.au **M:** 0409 936 503	Extensive research into mite species (pest and predatory species) and beneficial insects in vineyards.
David Madge	Entomologist	**DPI Mildura** T:(03) 5051 4500 E: david.madge@dpi.vic.gov.au	Organic viticulture: an Australian manual, organic pest management options and vineyard beneficials.

In addition to entomologists listed above, there are a number of locally based pest identification experts and businesses offering vineyard-monitoring services.

For more information contact your regional winegrowing association.

9.2. Preparing specimens for identification

Collecting samples

There will be occasions when you are not able to find particular arthropods in an existing pest guide and formal identification by an expert will be required. For reliable identification the specimens should be undamaged and in an appropriate development stage. Some species show considerable variation in size, colouration, shape and appearance between males and females, so where possible, 10 to 15 fresh specimens should be collected.

Documentation

It is important to collect accurate data to aide in successful identification and to label the specimen accurately, should it remain in an insect collection for future reference. Collection data labels should be written with pencil, as ballpoint ink may run or ruin the sample. The minimum information that should be recorded includes:

- Locality and date,
- Collector's name(s),
- Host plant or animal collected from
- Description of damage (type and extent)

Specimen preparation[21]

Place fresh, healthy insect specimens in a non-crushable container with small pinholes in the lid for ventilation. Place a small quantity of food on which the insects were feeding, in the container with a piece of tissue to absorb any excess moisture. If strong-jawed predatory insects are collected, place them in separate jars so they do not damage each other!

Where delays for correct identification are expected the following preserving methods can be used:

- Hard bodied insects can be killed and preserved in 70% alcohol or methylated spirits or by freezing. Never use water.
- Butterflies and moths should be killed by freezing for 24 hours or by placing them in an air tight glass container with a ball of cottonwool or tissue soaked in nail polish remover or acetone. After killing, place them gently in another container between layers of tissues.
- Larvae should be killed with water just at boiling point to ensure that they do not turn black and become difficult to identify. After boiling, the specimens can be transferred into 70% alcohol for preservation. Alcohol should not be sent by post.
- Soil dwelling animals can be placed in moist soil with the container topped up to minimise damage by shaking.

Starting your own insect reference collection

If you wish to start collecting insect specimens starter kits can be sourced from http://www.entosupplies.com.au/

Further information including a guide to 'Collecting and Preserving Insects and Mites' can be downloaded here. Another useful resource is:

Upton, M.S. (1991) *Methods for Collecting, Preserving, and Studying Insects and allied forms. 4th Edition.* The Australian Entomological Society. Brisbane, Australia.

For CSIRO information on simple methods of preserving insects and their allies (species specific) go to http://www.ento.csiro.au/education/preserving.html

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[21] *PIRSA and GRDC (2008) 'Crop insects the ute guide – Southern Grain Belt', Government of South Australia, PIRSA and GRDC.*

10. CHECKLISTS

10.1. How well do you know your vineyard pest and its enemies?

The following checklist can be used when prioritising the pest control strategy and your level of understanding about the pest.

Table 25: Checklist for prioritising your pest control strategy using beneficials.

Name	Question	Your Answer
1. Ecology of pest species and beneficials?	What are the most important (economically damaging) pests that require management in your vineyard?	
	What are the most important predators and/or parasitoids of the vineyard pest(s) identified?	
	What are the primary food sources, habitat and other ecological requirements of both the pests and beneficials? **Pests** - Where does the pest come to the vineyard from? - How is it attracted to the vineyard? - How does it develop in the vineyard?	
	Beneficials - Where do the beneficials come from? - How are they attracted to the vineyard? - How do they develop in the vineyard?	
2. Timing	When do pest populations generally first appear and when do pest populations become economically damaging (vine growth stage)?	
	When do the most important predators and parasitoids of the pest appear?	
	When do food sources (nectar, pollen, alternate hosts, and prey) for beneficials first appear?	
	How long do they last?	
	What insectarium plant species can provide habitat?	
3. Identification of strategies	Are you able to reduce the pest habitat via cultural means (ie reduce/ alter overwintering pest sites, or reduce/alter locations from which the pest invades)?	
	Are you able to augment a suitable habitat for beneficials (establish insectariums etc)?	
4. Insectarium establishment	What species (native or introduced) will you plant and where will you source seed and/or tube stock?	
	Consider the cost of ground preparation, planting and maintenance (irrigation, weeding, etc.) for: - At least one year following establishment of perennials, - How many insectarium plants are needed throughout the season to provide a suitable habitat to beneficials? - How will you monitor the success of your insectarium planting?	

10.2. Getting the most out of your insectarium

Phenology of grapevines, insectarium species and arthropods in the vineyard

Phenology is the study of the annual cycles of plants and animals and how they respond to seasonal changes in their environment.

By considering the natural life cycle of the key vineyard pests you wish to control, the lifecycle of beneficials and the growth cycle of insectarium plants, you can start to align these periods so they can be of use to you in the vineyard. For example:

- Planting dates of insectarium species to ensure they are flowering (producing nectar and pollen) and shelter when required by beneficials,
- Understanding the life cycle of vineyard pests, their likely times of economic impact and key timing for control, and
- Encouraging beneficial numbers to correlate with pest insect emergence for natural control.

Once you have considered the short list of plants you may like to incorporate in your insectarium, write the species down in the table below with an indication of their peak flowering times. Cross-reference this with the beneficial species you are aiming to attract and then monitor to see if you achieve success.

Table 26: Key flowering periods of insectarium plants selected for trial.

Key flowering period of insectarium species													
Scientific Name	Common Name	Month											
		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug

Table 27: Key periods of pest activity in the vineyard.

Key periods of pest activity in the vineyard													
Scientific Name	Common Name	Month											
		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug

Table 28: Key periods of beneficial arthropod activity in the vineyard.

Key periods of beneficial arthropod activity in the vineyard													
Scientific Name	Common Name	Month											
		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug

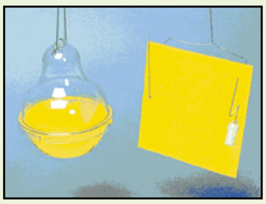
11. KEY REFERENCES

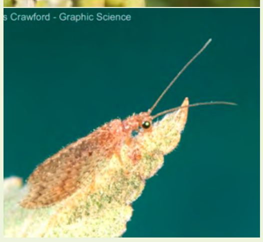
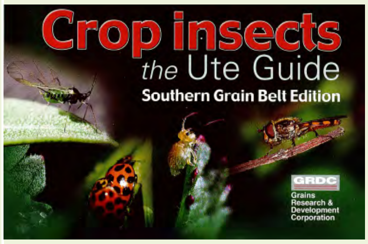
There are many sources of information available from libraries and the Internet. Some of the places to access relevant information about native plants, insectarium and arthropods identification are presented below.

11.1. Products

A range of books, and suppliers of beneficial insect products are available to assist you. A list of resources that may prove useful is provided below (and throughout the notes).

Table 29: Suppliers of beneficials and vineyard monitoring supplies.

Name	Website	Services	Items (click the item to find out more)
Australasian biological control (National)	www.goodbugs.org.au	The Association of Beneficial Arthropod Producers Inc (ABC Inc) - better known as the good bug producer website, includes lots of useful information.	
Biological Services (Loxton)	www.biologicalservices.com.au	Biological Services produces and supplies insect and mite predators and parasites to control a range of pests, mostly in horticultural orchards. They also sell pheromone traps and yellow sticky traps.	
Bug Central (Adelaide)	www.bugcentral.com.au	Bug Central provides a range of products and services to reduce the use of pesticides in home gardens. They also supply nematodes as a biological control option for millipedes in residential settings.	 
Bugs for Bugs (Queensland)	www.bugsforbugs.com.au	Bugs for Bugs produces a range of biological control agents and supplies. There is a broad range of useful information contained on the website.	 
Entosol Pty Ltd (Australia)	www.entosol.com.au	Entosol (Australia) Pty Ltd sells an extensive range of IPM monitoring resources.	

Name	Website	Services	Items (click the item to find out more)
IPM Technologies (Victoria)	www.ipmtechnologies.com.au	IPM Technologies is a company of experienced entomologists specialising in Integrated Pest Management. They are equipped to carry out research into the effects of pesticides on insect and mite pests and beneficials.	 
Grains Research and Development Corporation (National)	www.grdc.com.au/bookshop	This guide is designed to assist farmers to identify the most common insects found when monitoring field crops and pastures across southern Australia.	
		The back pocket guide to identifying beneficial insects in broad acre crops and snail identification and control has been developed by the GRDC. **Free copies** of the pocket guides are available from the GRDC (an order form can be downloaded from their website).	 

11.2. Websites

Support for selecting and planting plant species

Nature Maps (found on the 'Backyards for Wildlife' website www.backyards4wildlife.com.au/) can be used to source an indigenous plant species list appropriate for your local area. For more information go to http://www.backyards4wildlife.com.au/index.php?page=nature-map-instruction.

The **Australian Native Plants Society** website contains information on many of the native species you may consider incorporating in an insectarium. For more information go to http://anpsa.org.au/ The 'APS Query' program (download) enables the selection of Australian native plants to suit specific requirements (search for nectar and insects), see http://anpsa.org.au/download.html#query.

The **Native Grass Resources Group** have information about available native grasses, a database of grass seed suppliers and growers, and glossy publications, see http://www.nativegrassgroup.asn.au/

FloraBank - Information on native seed management. A range of guidelines, including basic germination and viability tests for native plant seed are provided www.florabank.org.au/default.asp?V_DOC_ID=880 along with an extensive range of practical tools, see www.florabank.org.au

Other useful sources for obtaining the growing requirements of plants:

- **State Flora SA** http://stateflora.com.au,
- **Australia's National Herbarium** http://www.anbg.gov.au/cpbr/databases/index.html
- **eFlora of South Austra**lia http://www.flora.sa.gov.au

Support for arthropod identification and knowledge

CESAR website for **Collateral Management for grapes in Australian vineyards Minimising the toxicity of pesticides to beneficial Invertebrates** is a good starting point for specialist knowledge regarding vineyard pest species, pictures of beneficials and chemical toxicity ratings, for more information see http://cesar.org.au/index.php?option=com_collateral_manage

Pest Notes are peer-reviewed publications about specific pests or pest management topics in California. Australia shares some common pest and natural enemy species, see http://www.ipm.ucdavis.edu/PDF/PESTNOTES/index.html (pests) or http://www.ipm.ucdavis.edu/PMG/NE/index.html (natural enemies).

Bugs for Bugs – For info on bio-control options for a range of crops, see www.bugsforbugs.com.au

CSIRO Entomology – Australian Insect Common Names database is a useful online resource for identifying insects. http://www.ento.csiro.au/aicn/ or the visual key to arthropods is a key to help you identify insects and arthropods to Order, see http://www.ento.csiro.au/education/key/couplet_01.html

What bug is that? A visual resource to help identify insects. An overview and description of each insect order is presented with photos, see http://anic.ento.csiro.au/insectfamilies/

Waite Insect and Nematode Collection - Are used by staff and postgraduate students to undertake identifications, see http://www.sciences.adelaide.edu.au/research/winc/

Identification for insect Orders, visual keys are used to help identify insects to order. Each order has detailed information, photos and links, see http://www.discoverlife.org/mp/20o?guide=Insect_orders

The Atlas of Living Australia – Has a range of resources, which are of interest to property owners. For example you can 'explore your area'. The website will automatically locate the plant species local to your area, see http://biocache.ala.org.au/explore/your-area and http://www.ala.org.au/

Insect collecting videos – if you are interested in watching a short video about collecting insects, installing pitfall traps, pinning insects etc, see http://lubbock.tamu.edu/ipm/AgWeb/videos/collecting/index.html

Cornell University's Biological Control website provides information on a range of natural enemies to pest species, see http://www.biocontrol.entomology.cornell.edu/index.php

11.3. Recent publications and articles related to insectariums

Bailey, M. (2010) ***Insectarium/vegetation corridors in established vineyards.*** The Australian and New Zealand Grapegrower and Winemaker, May – Issue 556. p 25-29.

Barnes, A.M, Wratten, S.D, and Sandhu, H.S. (2010) ***Biodiversity in vineyards: worth the bother?*** The Australian and New Zealand Grapegrower and Winemaker, September – Issue 560. p 25-33.

Barnes, A.M, Wratten, S.D, and Sandhu, H.S. (2010) ***Harnessing biodiversity to improve vineyard sustainability***. Proceedings of the Fourteenth Australian Wine Industry Technical Conference.

Bernard, M. et al (2010) ***Conserving biological control and preventing mite outbreaks in Australian vineyards: The effect of pesticides on a predatory mite indicator species***. Australian Viticulture, September/October, V4, No. 5.

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12. KEY DEFINITIONS

Key words used in these notes are presented below.

Item	Definition
Arthropod	Arthropods are members of the phylum 'Arthropoda' and are animals having an external skeleton, a segmented body and jointed appendages. This class includes insects, arachnids, and crustaceans.
Beneficial insects	Those arthropod species (naturally occurring enemies of vineyard pests) that assist in pest management in vineyards in preference to insecticide use.
Biodiversity	Biodiversity is the degree of variation of life forms within a given ecosystem. This includes the different plants, animals and micro-organisms present (and their interactions) in the vineyard.
Biodynamic viticulture	Biodynamic agriculture is a holistic approach to agriculture based on the teachings of the Austrian philosopher Rudolf Steiner as outlined in a series of lectures given in the 1920's.
Cultural	Activities directly involved in growing and management of healthy grape vines including soil management, canopy management etc which can reduce the effects of pest and disease populations by means other than by or in consideration of chemical application.
Ecosystem	The vineyard ecosystem is comprised of many different components including vines, other crop plants, volunteer plants, water, soil and soil organisms, beneficial and pest arthropods such as insects, beneficial and disease-causing microbes, and adjacent natural habitat.
Ecosystem services	The benefits gained, either directly or indirectly, from the sum total of functioning ecosystems (either natural or modified), which includes soil health and fertility, and biological control of pests and diseases ie beneficial insects helping to control pest species in a vineyard.
Endemic	Plants that are present at or associated with a particular area.
Farm scaping	Is a whole-farm, ecological approach to pest management. It can be defined as the use of hedgerows, insectarium plants, cover crops, and water reservoirs to attract and support populations of beneficial organisms, such as arthropods, bats and birds of prey etc.
Generalist	Is a plant or insect that either supports or preys on a wide range of organisms (opposite to a 'specialist').
Hedgerow	Hedgerows consist of lines or groups of trees, shrubs, herbs and grasses, many of them native species, which are planted along roadways, fences, field edges or other non-cropped areas and have the capacity to provide multiple ecosystem services to vineyards.
Host	A plant or animal that provides a location for reproduction (and/or food source) of arthropods.
Insectarium	Insectariums are vegetation plantings designed to provide shelter and food sources for beneficial arthropods within the vineyard.
Instar	A stage of growth between each moult of an insect's life between the egg and adult. LBAM larvae are often referred to by their instar stage.
Larvae	The immature stage of insects that have a complete metamorphosis such as beetles, moths, and flies. They are commonly referred to as a grub, caterpillar or maggot.
Organic agriculture	Organic grape growing involves the development and maintenance of sustainable vineyard systems that rely on natural processes where possible for nutrient cycling and pest, disease and weed management. For more information see **'Organic Viticulture: An Australian Manual'** at http://new.dpi.vic.gov.au/agriculture/farming-management/organic-farming/organic-viticulture
Parasitoid	An insect that survives on a living host when immature but becomes free-living as an adult.
Pest	A plant or arthropod species that is not wanted due to its adverse economic effect on grape vine production.
Predator	Any carnivorous arthropods.
Prey	Arthropods that are hunted or captured for food by another arthropod.
Specialist	An organism that has specific prey preference that is limited to a small range of similar species (opposite to a 'generalist').
True bugs	'True bugs' are from the order Hemiptera, they are characterised by the fact that they have piercing, sucking mouthparts.

Appendix 1

Information about regional environmental programs

wine growing for the future

Regional environmental programs

There are many good reasons to get involved in regional environmental programs. By engaging with your local wine growing group you have the opportunity to share your successes, as well as any failures that may occur along the way (so others do not make the same mistakes). You can encourage each other and it may be possible to pool knowledge and resources.

Joining a local winegrowing group is a great way to share information and to document your progress against biodiversity goals on your own property.

Regional initiatives provide a framework for you to assess your progress and link in with recognised benchmarking programs that can also be used towards environmental accreditation programs.

Examples of some of the current environmental initiatives occurring in your region are listed below.

EntWine Australia (National Focus)

EntWine Australia is a voluntary environmental assurance scheme developed by Winemakers Federation of Australia (WFA) that allows winemakers and wine grape growers to receive formal certification of their practices according to recognised standards.

For more information go to www.wfa.org.au/entwineaustralia/default.aspx

McLaren Vale Grape, Wine and Tourism Association (MVGWTA)

The ***McLaren Vale Generational Farming Project*** and ***McLaren Vale Environmental Management Plan*** provides a framework to assess your progress against a range of environmental and sustainability goals.

- *Linkages with **McLaren Vale Generational Farming Project** Chapter 3 - Biodiversity goals include:*
  - *To measure and record the biodiversity of your vineyard and surrounding land,*
  - *To take actions and to maintain your biodiversity and work to improve it in the long term,*
  - *To prevent reductions in biodiversity and reverse any decline on your vineyard/property,*
  - *To monitor and assess biodiversity within your vineyard/property and measure populations and species present,*
  - *To provide appropriate environmental conditions for the preservation and enhancement of biodiversity within your vineyard/property, and*
  - *To adopt vineyard management practices, which promote biodiversity and allow for the reduction of chemical inputs into the environment.*
- *Linkages to the **McLaren Vale Environmental Management Plan** action points:*
  - *Plant three key vegetation corridors linking key landscapes in the region established with land management plans for carbon capture and biodiversity benefits, and*
  - *Support the revegetation of creek lines and wine shelterbelts throughout the vineyards.*

For more information contact MVGWTA or go to www.mclarenvale.info

Adelaide Hills Wine Region (AHWR)

The Adelaide Hills Wine Region encourages all members to continually reduce their footprint on their natural environment, to the benefit of the environment and their business. A summary of environmental initiatives within the region is presented below:

- **AHWR Environmental Management Plan (EMP)**

  The AHWR is currently embarking on the development of a comprehensive strategic and practical Environmental Management Plan, aimed at genuinely assisting and facilitating the continual improvement of the personal, business and community relationship with our region's natural environment. The resulting EMP will be long-term in scope, clearly identifying short and medium term projects, in order to meet our long-term goals. The plan will aim to achieve these goals through knowledge sharing, support based networking, fund sourcing and relevant and integrated regionally directed projects. The resulting plan will address the environmental concerns of biodiversity, water, energy, waste, soil, climate vulnerability and will include a comprehensive Biodiversity Plan, guidelines for Environmental Best Practice and a regional Environmental Management System (EMS).

- **AHWR EMS Program**

  Since 2007 the AHWR Environment Committee has encouraged all members to consider implementing an EMS across their business and in so doing, has encouraged members to undertake the requirements of either the EcoMapping EMS system, or preferably seeking Freshcare environmental accreditation. Those implementing Freshcare and are willing to undertake an independent audit are eligible for EntWine membership. This allows winemakers and winegrowers to receive formal certification for their environmental practices and be more competitive in the marketplace.

- **AHWR Biodiversity Program**

  The AHWR Biodiversity Program is a multi-faceted program comprising of mostly new projects aimed at enhancing native biodiversity in our vineyard and winery environment. The program will fit within the overarching AHWR EMP and Biodiversity Plan.

  Projects within the program include:

  - **Biodiversity Audit (NatureLinks) and Related Projects**

    With the assistance of DENR NatureLinks Program, the AHWR is undertaking an audit of the region's 'state of biodiversity affairs' in order to raise awareness of the importance of healthy ecosystems for sustainable food and wine production, to achieve improved outcomes for biodiversity and to promote biodiversity conservation. Related projects currently being considered by the Environment Committee and relevant to the outcome of this audit include:

    - Remnant Paddock Tree Project,
    - AHWR Native Corridor and Tourist Trail (long term),
    - AMLR Bird Survey, and
    - Threatened Species sponsorship.

- **Integrating NRM in to Vineyard Production Systems**

  Through Adelaide and Mount Lofty Ranges (AMLR NRM) Board funding, the AHWR will be hosting a series of four field days aimed at raising awareness of and providing practical information for on grounds improvement works.

  1. Soil health and the role of soil organic carbon,
  2. How to manage healthy waterways,
  3. Managing remnant vegetation, and
  4. The role of native plants in and around vineyards.

- **Vineyard Biodiversity and Insect Interactions Workshop** (GWRDC Regional SA Central)

  Through GWRDC Regional SA Central funding, the AHWR will be hosting a workshop addressing the importance of vineyard biodiversity and insect biodiversity in particular, and methods to establish and monitor insectariums.

- **Biodiversity study with Flinders University**

  A post-graduate level study will be held across numerous AHWR vineyards between 2011 and 2013 looking at various invertebrate-plant interactions within the vineyard environment.

- **AHWR Environmental Champions Program**

  Many AHWR members are already committed to and implementing environmental improvement practices in their businesses. This program is a way of bringing together this community, sharing their unique stories, providing a support network and encouraging all members of the possibilities that exist to reduce our environmental footprint. Various subgroups are hoped to be formed comprising members addressing specific environmental improvements on their properties.

For more information about any AHWR Environmental activity contact Adelaide Hills Wine Region at natasha@adelaidehills.com.au or go to www.adelaidehillswine.com.au/

Langhorne Creek Grape, and Wine Incorporated (LCGWI)

A summary of environmental action at Langhorne Creek

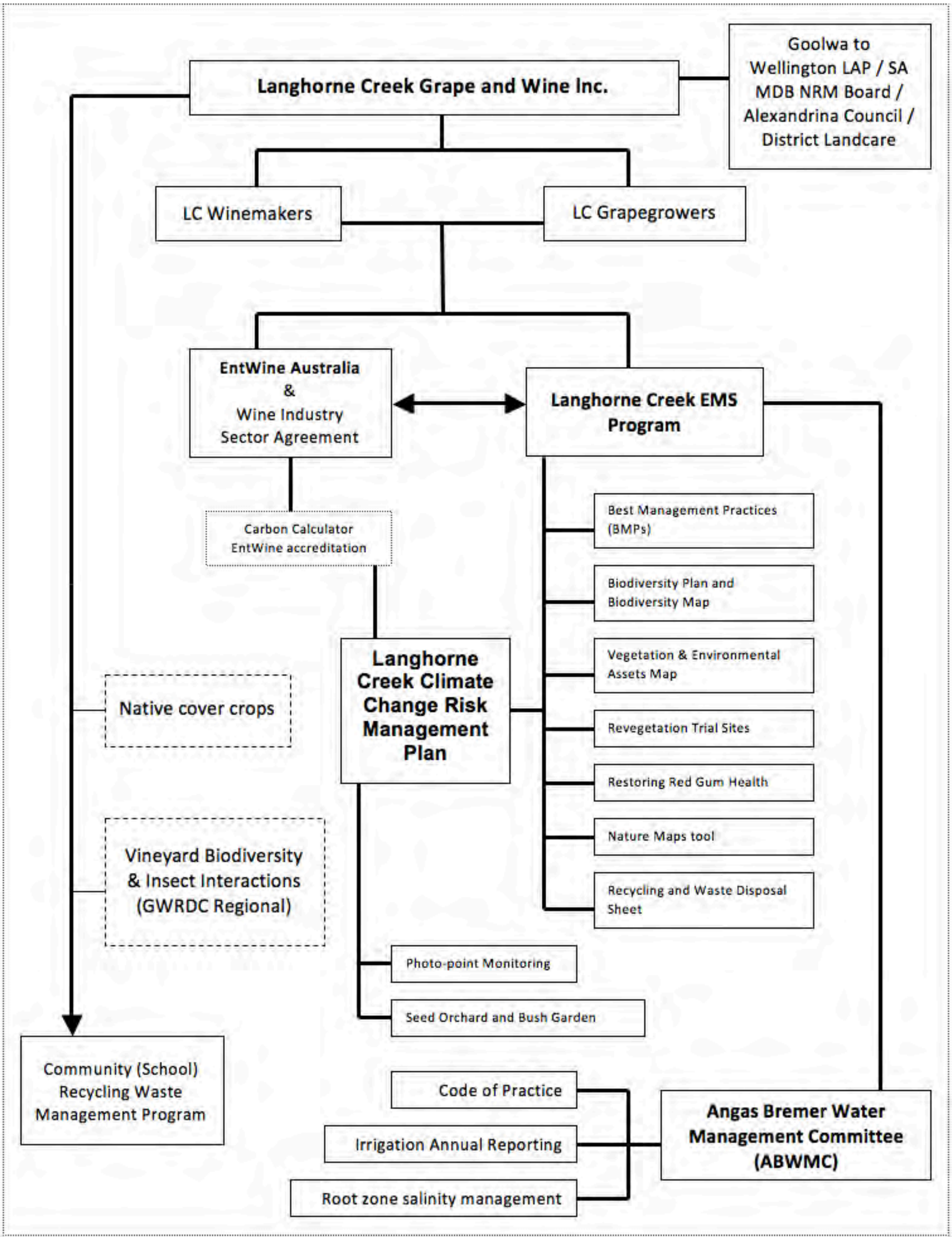
Through LCGWI the Langhorne Creek wine region has established a regional Environmental Management System (EMS). The EMS recognises and overlays the initiatives of the Angas Bremer Water Management Committee, which has lead to the development of related initiatives that support the environmental goals of the region.

A summary of some of the past and present Langhorne Creek wine region related initiatives include:

- The establishment of the Angas Bremer Water Management Committee, which has developed and introduced a mandatory code of practice for irrigation management. This includes the establishment of non-irrigated, deep-rooted vegetation (usually local indigenous) tied to water allocation.
- The establishment of a regional EMS, which introduced environmental stewardship to vineyards.
  - The EMS involved the undertaking of property environmental risk assessment and the development of environmental Best Management Practices (BMPs) to address identified issues.
- The establishment of a regional biodiversity plan and map for reference in property planning.
- Development of a regional recycling and waste management sheet and waste management plan.
- Undertaking a regional climate change risk management planning exercise and development of related policies and guidelines for land managers to support the regional objectives.
- Establishment of revegetation trial sites, including an Angas River riparian zone.
- The establishment of photo point monitoring sites to monitor long-term effects of climate variability.
- The development of a Regional Environmental Assets and Native Vegetation Map, useful for property planning and encouraging native corridor linkages.
- Participation in the development of EntWine Australia. Support for members to adopt EntWine, drawing on the established EMS, related BMPs and supporting tools.
- The introduction of NatureMaps to EMS participants for property planning to support their EMS and EntWine and the introduction of the Australian wine industry Carbon Calculator tool to participants to support the EMS and EntWine.

A small amount of work has also been undertaken to trial vineyard inter row planting of native species. It is hoped to build on this work in the coming years. A diagram of these projects and how they relate to each other is presented below.

Scope of Langhorne Creek environmental activities



For more information contact Langhorne Creek Grape and Wine Inc at www.langhornewine.com.au or Angas Bremer Water Management Committee Inc at www.angasbremerwater.org.au

Appendix 2

Key articles relating to the establishment of insectariums and the role of beneficial arthropods in Australian vineyards.

Mid-row crop management options to improve vineyard performance and profitability

By Tony Hoare
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Mid-row management can have a significant influence on the yield and quality of winegrapes. The mid-row can be a useful tool to improve vineyard performance and profitability. Mid-row management can have a direct benefit to irrigation, pest and disease control, yield, nutrition and the overall profitability of a vineyard.

Vineyard mid-row management can be a useful tool for reducing the following:

- water usage
- pest and disease pressure
- weed pressure and reliance on chemical herbicides
- fertiliser requirements
- slashing
- soil compaction
- soil erosion.

Traditionally, cereal and some broadleaf crops have been cultivated for benefits such as improved organic matter, soil water retention, biofumigation of soil-borne pests and diseases, under-vine weed suppression and erosion control. Mid-row crops are also a great tool to manipulate vine vigour and yield and, therefore, improve overall vine balance. I have implemented the following options for mid-row management in recent years for targeted areas of vineyard improvement in profitability and productivity.

ROLLED COVERCROPS

Cereal crops of oats, triticale and some broadleaf crops, such as faba beans and mustards, can be used for this technique either on their own or preferably in a mixture. The use of rolled crops is particularly good in sandier soils that have good winter rainfall and little of no summer rainfall. This technique seems to work best on sandier soils that are less prone to soil structure damage from annual cultivation compared with heavier soils with a high clay content.

Autumn sowing is the best time while the soil is dry and workable; there is still warmth in the soil for seed germination and season-breaking rains help rapid establishment before bird damage and reduced seed viability. Spring sowing can also achieve good growth, however, rainfall is not as predictable and the soil maybe more difficult to work after winter rains.

Figure 1. A rolled crop of oats and triticale in McLaren Vale, South Australia.

Application of a starter fertiliser aids rapid growth and assists in the production of as much bulk as possible in the crop. The thicker the crop, the better the matting effect once rolled and the crop residual benefits can last for more than one season.

The crop can be rolled at any time when you are satisfied with the growth and can work it into your schedule. There is no critical time for rolling, however, allowing the crop to reach seed maturity can provide seed and avoids the need to cultivate and sow the following season. The crop can be sprayed out with a herbicide prior to or during rolling, however, many crops will die off naturally after rolling. Rolled cover crops are very useful for increasing vine vigour in low vigour situations. They can be used as a part of precision viticulture management for low vigour sections of vineyards that maybe compromised by neighbouring trees, shallow soils, etc.

ROLLED CROPS VERSUS SLASHING

The benefits of rolling a cover crop far outweigh those of slashing a cover crop. Slashing the covercrop breaks the

Figure 2. A freshly rolled covercrop in McLaren Vale, South Australia.

crop into smaller pieces that are then quickly lost in windy weather or broken down early in the season. The stubble that remains after slashing allows weed growth and soil moisture to escape. In contrast, rolling a crop will provide a thick ground cover that suppresses weeds and holds soil moisture. The rolled crop is not affected by wind as the roots are still attached to the stem and the residual can last for more than one season.

The main benefits of a rolled crop are:

- Savings in tractor time and labour

No seasonal maintenance of the mid-row with slashing or herbiciding. This is a benefit during the busiest time of year when other vineyard jobs can take precedence.

- Water savings

Mulch from the rolled crop in the mid-row reduces soil moisture loss and eliminates competition from weeds for soil moisture. It cools soil temperatures and lowers the risk of leaf/bunch scorch in heatwaves from reflective soils. Soil structure is improved and it allows greater moisture infiltration through a better-drained soil surface. Soil moisture is also retained through improved soil moisture resulting from a higher organic matter content.

- Improved soil health

This occurs through increased levels of organic matter, earthworm and other invertebrate activity, reduced compaction and lesser risks of wind and water erosion.

- Savings in under-vine herbicides

A reduced weed seed bank in the mid-row reduces the likelihood of weed seed spreading and germinating under-vine. Noxious weeds, such as caltrop, three-cornered jack and innocent weed, are effectively suppressed by rolled covercrops.

- Aesthetically very pleasing

CHARACTERISTICS OF VINEYARDS THAT SUIT ROLLED COVERCROPS

- Sandy soils
- Soils in which it is difficult to establish permanent swards
- Low vigour vineyards
- Where water supply is limited/ expensive
- New vineyard plantings
- Noxious weed pressure, especially creeping weeds such as caltrop, three-cornered jack and innocent weed.

WHITE ALYSSUM (*LOBULARIA MARITIMA*)

White alyssum is an exotic perennial from southern Europe that has been found by Australian researchers to be a valuable nectar source for *Trichogramma carverae*, a known parasitoid of the grapevine pest lightbrown apple moth (LBAM). The Trichogramma wasp uses the white alyssum flowers as a pollen source. Planting white alyssum in every tenth vine mid-row has been estimated by Bernard *et al.* (2007) to provide a pollen source that will attract and sustain a population of *Trichogramma* sp. in a vineyard. It is thought that another predator of LBAM, the brown lacewing, is also attracted to white alyssum as a pollen source. The timing of flowering for the alyssum is important to attract the wasps and the other beneficial insect predators prior to the larval stage of the LBAM lifecycle.

White alyssum seeds are tiny and really need to be mixed in with sand or another media when sowing. The best time for sowing is in the warmer months of autumn, spring or early summer. Soil moisture will be required to germinate seeds; after establishment it can survive with periodic rainfall. Subsurface irrigation was installed at Kangarilla Road Wines, in McLaren Vale, to assist in establishing alyssum in the mid-rows of every tenth row. At Kangarilla Road, the mid-rows were hand seeded with a fairly patchy result initially (see Figure 3). Ultimately, this was not a big issue as the alyssum spread fairly quickly and was able to out-compete most weeds whilst becoming established.

Vineyard suitability of white alyssum

- Suits most soil types
- Vineyards with a history of lightbrown apple moth activity, including those with susceptible varieties to lightbrown apple moth, e.g., Chardonnay, Riesling, Semillon.
- Where weed suppression is required

SALTBUSH (*ATRIPLEX SEMIBACCATA* AND *ENCHYLAENA TOMENTOSA*)

Native prostrate saltbush species are a potential mid-row management tool with multiple benefits. I stumbled across a ruby saltbush growing naturally in a vineyard in McLaren Vale. It had established itself in a mid-row that had not been worked for a number of seasons (figure 5). Dr Chris Penfold, from The University of Adelaide, has been researching the use of saltbush as a mid-row crop and has found some interesting results.

Saltbush is well suited to most soil types and are salt tolerant. It is thought that saltbush could also have the potential to export salt from soil in vineyards with the aid of a fodder-harvesting machine. Sheep will graze saltbush without it being removed completely, so it is well suited to organic and biodynamic vineyards where livestock are, in some instances, used for winter weed management.

Saltbush is easy to establish, however was found by Penfold to have a competitive effect with vines for water and nutrients which was thought to reduce yield. Therefore, saltbush is more suited to a situation where vine vigour and yields are excessive. Saltbush is a perennial plant and will continue to grow all year round if given a light trimming with a slasher. A slasher set high will keep the saltbush low to the ground. Under-vine creeping can be controlled with discs and/or under-vine herbiciding. When using systemic herbicides undervine, care is needed to avoid any drift and off-target damage onto parts of the saltbush.

The prostrate forms of saltbush form a thick mat on the soil surface that provides ideal conditions for earthworm and invertebrate activity. Also observed in the Penfold trial was a much higher

Figure 3. The results of hand seeding of white alyssum at Kangailla Road Wines, McLaren Vale, after germination.

Figure 4. Newly-germinated white alyssum (top) and their fragrant blooms (bottom).

predation of lightbrown apple moth eggs where saltbush was planted compared with grass and ryegrass. The berries produced by the ruby saltbush are also considered a good source of bush tucker. If weed suppression is also required then this is a well-suited mid-row crop.

Vineyard suitability of saltbush

- High vigour vines
- Good water supply
- Saline soils/irrigation water
- Difficulty in establishing other swards and mid-row crops
- Livestock grazing
- Weed suppression required

CHICKORY

Chickory is a broad-leafed perennial that has a deep taproot. The benefits of chickory for mid-row management are in high-vigour sites where vigour cannot be controlled by other methods. From my experience, chickory is easy to

Figure 5. Ruby saltbush (*Enchylaena tomentosa*) in McLaren Vale, South Australia, found growing naturally in the mid-row of a vineyard.

Figure 6. The leafy bulk of chickory after one growing season (top) and an attractive chickory flower (bottom).

establish, however, I have spoken with vineyard managers who found it more difficult, especially in dry conditions.

While slow to establish, chickory provides excellent weed suppression once it reaches full maturity. Once at full maturity, chickory has a taproot that will penetrate hard-packed soils and help improve soil drainage and aeration. The leaves of chickory can be used for salads although they can be very bitter.

Vineyard suitability of chickory
- High vigour vineyards/varieties
- Heavy soils with high clay content
- Compacted soils
- Waterlogged soils
- Summer rainfall regions
- Highly fertile soils with high excessive nitrogen.

CONCLUSION

Post-harvest weather conditions are usually the best time for soil preparation and establishing a mid-row strategy. A well-researched and implemented mid-row management strategy can yield a benefit in the following season and for many seasons to follow. While initial establishment is an expense, the cost can be amortised over the expected lifespan of the crop, which can be many seasons. When considering mid-row management options there are many different crops with specific requirements for climate and rainfall to maximise growth. The examples provided in this article have all worked well in the McLaren Vale region of South Australia and local advice should be sought prior to planting to ensure their suitability to your regional and site conditions. Dr Chris Penfold will be releasing a weblink on the website of the Grape and Wine Research and Development Corporation (www.gwrdc.com.au) in the near future as a reference guide for the selection and suitability of mid-row cover crop options.

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Cost benefit analysis of shelterbelt establishment: Natural enemies can add real value to shelterbelts

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It is well established that woody vegetation immediately adjacent to vines can enhance natural enemies and their contribution to pest control (Thomson and Hoffmann, 2009; 2010). In vineyards there are many opportunities to add vegetation – on land requiring restoration such as riparian zones along waterways and eroded areas, or on land unsuitable for productive grapegrowing due to salinity, water logging or requirements for wastewater disposal. There will always be a cost to the establishment of such vegetation, and in this article we present an analysis of the likely costs incurred and the potential benefit this may bring in terms of increased abundance of natural enemies. The analysis is based on extensive surveys of vegetation, and abundance and diversity of natural enemies in the adjacent vineyards in Victoria and South Australia (Thomson and Hoffmann, 2006, 2008). Across these sites, shelterbelts adjacent to vineyards are typically in the range of 4 to 10 metres in width. Costs are variable depending on whether the grower undertakes the revegetation or contracts the work to an outside agency, and also depending on the length of associated fencing. We outline some common factors to consider in estimating costs and then calculate the likely costs of establishing a shelterbelt under two scenarios. We also estimate the potential benefit to production in contributing to pest control within a vineyard. Comparison of costs and benefits reveals a substantial gain over the life of the vegetation.

Costs associated with establishing vegetation

Three methods of revegetation are commonly used:

1. **Assisted natural regeneration** in which no seed or seedlings are added to the site, but seed stores from remnant trees and shrubs, and/or seed stores already present in the soil are encouraged to germinate. Assisted natural regeneration relies on having adequate seed stores available either in remaining trees, shrubs and grasses in the area, or in the soil of the area being regenerated (Casey and Chalmers, 1993). The primary factor affecting success of assisted natural regeneration is the preparation of an adequate receptive seedbed around existing remnant vegetation in which seeds can germinate and grow, and the exclusion of grazing (usually by constructing fencing) which might otherwise destroy new growth.

2. **Revegetation by direct seeding** in which sites are seeded and fenced to achieve revegetation.

3. **Revegetation using seedlings** in which seedlings are first grown in nurseries and then transplanted to the revegetation site.

Common costs incurred in revegetation projects under these options may include project planning and management, transport costs for machinery/seeds/ seedlings/personnel, mechanical and chemical site preparation, fencing, weed control, seed and direct seeding costs or seedlings and seedling establishment costs, and tree guards/stakes. Several types of costs decrease on a per hectare basis as the size of the revegetation project increases. These include fencing, site preparation, line/boom spraying of herbicides, and direct seeding, most of which can be attributed to a fixed cost per project for mobilisation and transport of equipment. Other cost components including seedlings, seed and tree guards are more likely to be independent of ▶

the size of the project, i.e. their cost per hectare does not change with project size, except for the bulk buying of components.

Site preparation usually involves two elements: weed control and soil disturbance. Both aim to allow seed or seedlings to grow more easily. A range of mechanical site preparation techniques is available – commonly deep ripping alone or associated with cultivation. The average cost per hectare by a contractor is A$60 for deep ripping only (tractor and ripper) or $140 for deep ripping and cultivation. Costs will be reduced for projects undertaken with a large in-kind contribution by growers, or undertaken using machinery owned by organisations such as landcare groups or Greening Australia. For a grower using their own ripper and tractor, it is estimated that deep ripping would cost 1.2 hours labour per hectare plus a set-up time of 30 minutes to 1.5 hours labour. Pre-planting weed control is commonly undertaken with boom spraying, and post-establishment weed control by spot spraying. Weed control prior to establishment of new plants will reduce competition for nutrients, water and light, and usually uses a knockdown herbicide only, most commonly glyphosate, or less commonly a combination of knockdown and residual herbicide, with simazine the most commonly used residual herbicide. With labour, equipment hire and herbicides, the cost of boomline spraying in preparation to planting by a contractor is estimated at about $90 per application, and three applications are common. However, if the grower has access to machinery (as is commonly the case) the cost will clearly be reduced. Chemical costs, at $15-$30 per application of glyphosate or other knockdown chemical applied at 1-2 litres/ha, will depend on the number of applications required to achieve control. Again, we have not considered machinery costs as they are too variable – depending on access to tractor/boomline sprayer, either on site or through a local Landcare organisation. Machinery owned by a grower or local organisation will clearly significantly reduce costs compared with either hire of machinery or contracting this component of revegetation.

Tree guards and stakes are often put in place when planting seedlings for protection from rabbits and other small browsing fauna, or to enhance growth due to the 'greenhouse effect'.
Photo courtesy of Greening Australia

Vegetation may be put in place by direct seeding or planting seedlings of various sizes. For direct drilling and planting seeds, the major variable is whether the grower is undertaking the revegetation or employing a contractor. Seed is available for $250/ha compared with a rate charged by contractors of about $400/ha plus labour costs. The cost of hiring a direct seeder will contribute to grower costs, although direct seeders are made available by interested commercial enterprises such as Alcoa (the Alcoa Machinery Loan Scheme) at about $30 per day (Greening Australia, 2009). If seedlings are used rather than direct seeding, the recommended rate of planting is 1000/ha and the cost of these depends on the size of the seedlings and the size of the order. We estimate costs using smaller seedlings bought in quantity (80 cents/seedling for purchases of more than 1000), but more advanced seedlings will cost up to $6 each (200-300 millimetre pots). Seedlings may be planted by hand or by a mechanised planter. There will be greater labour costs with the former (contractor: 50c/plant, labour and ▶

VINE TALK

Many areas now would be pretty much in to the busy vintage period and there are a couple of reminders that need to be consider before the vines head in to dormancy.

It is important that you maintain the health of you vine leading in to dormancy and in making your decisions consider the length of the recent growing season, the yield of the vines and look at their general appearance. Nutrition and irrigation management play a critical role in maintaining the health of vines in this post harvest period.

For those of you out there looking to maintain growth on young vines leading in to dormancy or trying to maximise carbohydrate storage in your mature vines consider what you are planning to do in regards to your post harvest nutrition management of you vineyards carefully. Stored carbohydrate reserves can vary substantially during a season, but also from one season to the next, and can impact the performance of vines in the following spring.

Irrigation management post harvest needs to also be carefully considered and in terms of irrigation management, the strategies that you use need to be similar to your irrigation management strategies used from veraison to harvest. In general terms your irrigation management practices should keep enough moisture in the soil profile to allow the vine to store adequate carbohydrate levels for the coming season but not enough to stimulate new vegetative growth.

Pests and diseases can still cause problems after harvest by reducing the number and performance of functioning leaves, you should therefore keep an eye out for any potential pest or disease outbreaks and take the appropriate measures.

It is also a good idea to pay attention when having a look around during and after harvest at your vines as this can often lead to identifying where diseases or insects are or were a problem, discussions with your viticulturalist or winery viticulturalist at this time of time also play a crucial role in planning for next season. These two practices will allow you to formulate your diseases and insect management plans for these problem areas for next season.

Consult either your viticulturalist or winery viticulturalist when making any decisions on post harvest nutrition applications

Finally, always remember to seek professional advice for your specific situation.

Vine Talk is compiled by Scott Mathew, agronomist, Syngenta Tech Services.

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hire of hand planter) and greater machinery costs with the latter (commercial hire of mechanised planter may be $100/hr, although again some are available through community organisations or similar for $20/hr or even free). The labour costs vary widely with the skill of the planters, with three to four labour hours per 100 seedlings quoted for contractors, six to 20 hours for experienced farmers/volunteers, and 20-96 hours for inexperienced volunteers.

And then there is protection for the revegetation, fencing for the whole area, and individual tree guards. Tree guards and stakes are often put in place when planting seedlings for protection from rabbits and other small browsing fauna, or to enhance growth due to the 'greenhouse effect'. There is a range of practices here – they may be made 'at home' with materials such as cartons or cut-down plastic bottles to cost as little as 17c, but if purchased with the seedling they may add as much as $1 to the cost of each plant.

Fencing is a major cost of any revegetation project. Fencing is generally included to exclude livestock and native/feral animal species, but it may not be considered essential for vineyards where there are generally no grazing animals and the cost of rabbit proof fencing may be difficult to justify. A range of fencing is possible with the extremes being a plain wire fence ($1100 per kilometre) and a rabbit proof fence (one barbed, four plain wire, rabbit mesh, 90 centimetres high plus 15cm buried – 105cm total, cost: $3550/km) with additional labour costs. We used the cost of a plain wire five stranded fence and compared this with no fencing. Obviously fencing costs depend on the shape of the revegetated area. The common configuration seen in vineyards is lineal, along roads, between blocks, along water ways, and around sheds. The cost of fencing is greatly increased for lineal configurations. A 'square' hectare requires 400m of fencing, but a hectare of shelterbelt 4m wide would require 5km of fencing if fenced on all sides. We detail the cost of establishing 1ha of shelterbelt 4m wide (2500m long) and 10m wide (1000m long) by a contractor and a grower, with and without fencing (Table 1), and use this to calculate the cost per 100m of shelterbelt for comparison (Table 2).

We use the cost of revegetation with seedlings as this appears to be the most common approach in vineyards (pers obs, Greening Australia), although this is more expensive than assisted natural regeneration and seeding. However, there is little hard data on the relative success of the different methods in regions and on different sites. Without a better understanding of the success of different methods, it is not possible to assess whether a method that is cheaper at the establishment phase is really the most cost effective revegetation option available. ▶

Table 1. An example of the cost of establishment of a shelterbelt (4 metres and 10m wide) by a contractor or grower using seedlings, with and without the most economical fence (five stranded wire).

¹ The smallest used. Tubestock, the most commonly used, range from $1-1.30 each.

Contractor			**Grower**		
Cost description	Cost/ha for vineyard shelterbelt ($) a 4m (4m x 2500m) b 10m (10m x 1000m)		Cost description	Cost/ha for vineyard shelterbelt ($) a 4m (4m x 2500m) b 10m (10m x 1000m)	
	With fencing	Without fencing		With fencing	Without fencing
Site preparation using contractor deep ripping	60	60	Site preparation deep ripping. No machinery cost, in-kind labour at $15/hr	15	15
Fencing materials @ $1100 per kilometer (plain wire)	a 5508 b 2461		Fencing materials @ $1100/km	a 5508 b 2461	
Fencing labour @ 44 hours labour/km = $1500/km Labour cost estimated at $34/hr	a 7512 b 3357		Fencing labour, in-kind, labour cost estimated at $15/hr $660/km	a 3305 b 1477	
Boom spraying three times @ $89/ha/application	267	267	Boom spraying three times chemical cost only	90	90
1Seedings 80c/seedling	800	800	Seedlings 80c/seedling	800	800
Plastic guards plus stakes	1000	1000	Grower supplied milk carton or similar guards and stakes	170	170
Mechanised planting @ 50c/plant labour and planter hire	500	500	Mechanised planting hire planter @ $100/hr	100	100
Total cost per ha contractor	a 15710 b 7877	2607	Total cost per ha grower	a 9992 b 5113	1175

Estimation of benefit of natural enemies provided by presence of vegetation adjacent to a vineyard

We estimate the value of vegetation to pest control by calculating the value of the natural enemies provided if these animals were purchased from commercial suppliers. There is a limited number of species available for purchase – we use the value of these in our calculation. With the exception of *Trichogramma*, these are used as examples as there is an amazingly diverse range of natural enemies present in vineyards, far beyond the species that are commercially available. The commercially available natural enemies include: two parasitoids (*Trichogramma* for light brown apple moth control and *Aphytis* for scale control), several ladybird beetles including *Chilocorus* for scale control and *Cryptolaemus* ('mealybug destroyer') for mealybug control, a staphylinid or rove beetle, *Dalotia coriaria* (Kraatz) and several predatory mites, and generalist predator green lacewings, *Mallada signata* (Schneider). Note that not all of these are identified as relevant to vineyard pest control.The existence of vegetation adjacent to a vineyard increased the abundance of a range of natural enemies in the vine canopy (Table 3). The value of adjacent vegetation to the grower is at least $516-$696 per year for each 100m of native vegetation shelterbelt of 4-10m width. It is also important to emphasise that in this we have only considered a small number of the diverse range of natural enemies enhanced by vegetation. If a value could be put on all these, the overall value is likely to be much higher.

The cost of establishing a typical 4m (10m) wide shelterbelt, as commonly found associated with vineyards in Vic and SA, ranges from $628 ($788) per 100m for fenced shelterbelt put in place by a contractor to $47 ($88) for an unfenced shelterbelt put in place entirely through grower provided labour and machinery. The minimum benefit derived from 100m of shelterbelt is $516-$596. Based on the costs and benefits estimated here, there will be a net gain for every year except the first year for a fenced shelterbelt installed by a contractor. For a shelterbelt lifetime of 20 years, with benefit in terms of natural enemies being derived from conservatively the fifth year, this represents a net gain ranging from $7462 for the most expensive option (fenced 10m shelterbelt installed by a contractor) to $8203 for an unfenced 4m shelterbelt installed by the grower (Summarised in Table 4).

Table 2. Cost per 100 metres of establishing shelterbelts of common widths in vineyards in Victoria and South Australia.

Established by	With fencing		Without fencing	
	Cost/ha a. 4m x 2500m b. 10m x 1000m ($)	Cost/100m for a. 4m x 2500m b. 10m x 1000m ($)	Cost/ha a. 4m x 2500m b. 10m x 1000m ($)	Cost/100m for a. 4m x 2500m b. 10m x 1000m ($)
Contractor	15,710 7877	628 788	2607	104 216
Grower	9992 5113	400 510	1175	47 88

Table 3. Natural enemies increased by adjacent vegetation in vineyards in Victoria and South Australia, and the value of these calculated based on price from commercial suppliers.

Natural enemy	Examples from what is commercially available	Price/unit ($/unit)	Increase in abundance/ha	Value/100 m shelterbelt ($)
Parasitoids	Trichogramma Aphytis	0.0009 0.0044	5673	5.00
Ladybird beetles	Chilocorus, Cryptolaemus	0.40 0.28	1200	480-660
Staphylinid beetles	Dalotia	0.06	520	31.00
Total value for 100m vegetation				516-696

Table 4. Summary of overall benefit cost for 100 metres of vegetation 4m or 10m wide with a lifetime of 20 years.

Established by	Fenced/ unfenced	Width(m)	Cost ($)	Benefit /year ($)1	Net gain first productive year1	Net gain over 20 years2 ($)
Contractor	Fenced	4	628	550	-78	7622
		10	788	550	-238	7462
	Unfenced	4	104	550	446	8146
		10	216	550	334	8034
Grower	Fenced	4	400	550	150	7850
		10	510	550	40	7740
	Unfenced	4	47	550	503	8203
		10	88	550	462	8162

[1] Mean value based on our measurements in vineyards with shelterbelt widths 4-10m. It is possible that natural enemy abundance will vary with width.

[2] Assuming production of natural enemies at the rate assessed in our studies for five to 20 years post establishment, with a single establishment cost.

Other issues when computing costs and benefits

We account only for the benefits and costs of the project to the grower – effects of establishment/increase of vegetation may be broader through social, environmental and employment effects. The latter includes social or environmental benefits that may enhance the position/image of the industry and/or limit potential negative effects of viticultural activities. Vegetation may make it easier to continue to farm near residential boundaries. This might include attributes such as protection from spray drift, noise, or the visual impact of farm sheds or processing plants, and also more esoteric attributes such as visual amenity of the area, contribution to tourism through encouraging visitors, and cellar door sales. While these benefits are not included here, they may nevertheless be substantial and help growers offset costs. Although communities might benefit from revegetation projects without contributing to costs, they may contribute labour and funding in some instances. Our assessment also excludes the benefits or costs of currently non-marketed commodities such as potential future carbon accounting and contribution to pollution remediation.

We also do not consider the value of the land. There are two aspects to this – imputed lost value and imputed gained value. If the land given over to revegetation could have otherwise been used for grapegrowing, there has been potential income lost. However, revegetation is generally designed to be integrated with block boundaries to allow maximum production to continue, such as plantings along fence boundaries, and small block plantings in gully and waterlogged areas. There are also potential tax deductions associated with introduction of vegetation. If land is either retained as remnant or revegetated and a covenant is placed on the land so that future development is not possible, a tax deduction for the value of the land may be allowable. Some municipalities provide rate exemptions for this portion of the land. However, there is too much variation in these factors to include them in our cost/benefit calculations. We have also not considered other costs which may be incurred, such as site specific costs due to slope, rocks, fertiliser application or watering, erosion control matting, the use of mulch or straw to suppress weeds, reduced water loss, or further spraying to continue weed control.

Finally, we re-emphasise that the estimated direct benefits in terms of pest control come from a consideration of only five natural enemies that can be valued commercially. In a typical vineyard there are at least 20 different major classes of natural enemies whose value cannot be computed but which is nevertheless providing important ecosystem services to growers. ■

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Vegetation increases abundance of natural enemies of common pests in vineyards

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Vegetation exists adjacent to vineyards for a variety of reasons. It may be remnant or planted to provide protection from chemical drift, corridors for wildlife, shelter for stock, treatment of soil salinity, revegetation to rehabilitate waterways or removal of waste water by providing a soak with associated transpiration. Previous research has shown a variety of natural enemies including parasitoids, spiders, beetles and predatory mites can increase in crops adjacent to vegetation (Tsitsilas *et al*. 2006), and this is supported by our research at one vineyard in the Yarra Valley reported in GGWM (Thomson and Hoffmann, 2006a). We asked are these effects of vegetation adjacent to vineyards on the natural enemies of vineyard pests consistent across a range of vineyards with remnant and shelterbelt vegetation? Here we report results from seven vineyards in Victoria and are currently analysing data from a further 30 sites across Victoria and SA.

Role of natural enemies in controlling vineyard pests

A range of vineyard pests can impact on grape production: the most widespread are caterpillars or larvae of light brown apple moth (LBAM). Less frequently, or less widespread in any given season, are mealybugs (particularly long-tailed mealybugs), scale, weevils, Rutherglen bug, fig longicorn, larvae of pink cutworm, thrips, caterpillars of grapevine moths and wingless grasshoppers. For all these pests there is enormous potential for natural enemies to make a significant contribution to their control. Natural enemies are always there ready to respond to pest invasions, they can access hard to reach pests like LBAM protected in webbing in grape bunches or leaf rolls, mites in leaf buds, mealybugs under bark or in trellis pole gaps, adult scale protected by a hard protective cover and weevil larvae in vine canes.

Many natural enemies like spiders, brown and green lacewings, ladybird beetles and predatory bugs are familiar and visible in vineyards (Buchanan and Amos, 1992; Thomson *et al*. 2007). These can all make an important contribution to pest control, but there are many other much smaller but important natural enemies, predatory mites and parasitoids. Predatory mites contribute to control of hard to reach eriophyoid mites. Parasitoids, commonly wasps but sometimes flies, these insects, often tiny (including the smallest known), lay their eggs inside eggs, larvae or pupae of LBAM, scale, mealybugs and even weevils or other pest beetles and instead of the emergence of a pest to do more damage, another generation of parasitoids emerges to parasitise more hosts. The range of parasitoids known to attack vineyard pests (Thomson *et al*. 2007) is constantly expanding (eg Paull and Austin 2006).

The best known parasitoid in vineyards is Trichogramma (Figure 1) active in control of LBAM in all vineyards (Buchanan, 1977; Danthanarayana, 1980; Glenn and Hoffmann, 1997; Thomson *et al*. 2003). A single female will parasitise an entire raft of light brown apple moth eggs and instead of 20-70 light brown caterpillars hatching, 20-70 Trichogramma emerge to parasitise more eggs (Figure 1). A single female may parasitise as many as 40 eggs in two

Fig. 1. (Top) *Trichogramma carverae* (female) on LBAM egg mass from laboratory colony (laid on plastic cup) and (bottom) LBAM egg mass, fully parasitised. Holes in each LBAM egg are emergence holes for adult Trichogramma.

Table 1. Description of remnant (existing prior to vineyard) and shelterbelt (planted after vineyard) vegetation. There is understory at each site consisting of predominantly exotic grasses: Yorkshire fog *Holcus lanatus* L., phalaris *Phalaris aquatica* L., browntop bent *Agrostis capillaries* L., brome *Bromus diandris*. L., perennial rye grass *Lolium perene* L., couch grass *Cynodon dactylon*, L. with milk thistle, *Sonchus oleraceus* L. (F. Asteraceae), plantain medic *Plantago lanceolata* L. (F. Plantaginaceae), white clover *Trifolium repens* L. (F. Papilionaceae) and a saltbush, fat hen *Chenopodium album* L. (F. Chenopodiaceae).

Category/ Site	Trees and shrubs common name scientific name (Family)
SB1	red flowered paperbark, *Melaleuca hypericifolia* (Myrtacea), heath tea-tree *Leptospermum myrsinoides* (Myrtacea), black wattle *Acacia mearnsii* (Fabaceae), Spanish heath *Erica lusitanica* (Ericaceae), swamp gum *Eucalyptus ovata* (Myrtaceae), blue gum *E. globulus* (Myrtaceae)
SB2	red flowered paperbark, heath tea-tree, black wattle, Spanish heath, swamp gum , blue gum, Burgan *Leptospermum phylicoides Myrtaceae*
SB3	Blackwood *Acacia melanoxylon* (Fabaceae/Mimosaceae), prickly tea-tree *Leptospermum continentale* (Myrtaceae), prickly Moses *Acacia verticillata* (Fabaceae/Mimosaceae), *Eucalyptus* sp. (Myrtaceae), manna gum *Eucalyptus viminalis* (Myrtaceae)
SB4	*Eucalyptus* sp.(Myrtaceae), swamp paperbark *Melaleuca ericifolia* (Myrtaceae), blackwood, tea-tree *Leptospermum* sp. (Myrtaceae), *Callistemon linearis Myrtaceae*, wooly tea-tree *Leptospermum lanigerum Myrtaceae*
SB5	Swamp gum, river bottlebrush *Callistemon sieberi* (Myrtaceae), Furze Hakea *Hakea ulicina* Proteaceae, Burgan *Leptospermum phylicoides* (Myrtaceae), honey bracelet myrtle *Melaleuca armillaris* (Myrtaceae) Flinders Range Wattle *Acacia iteaphylla* (Fabaceae/Mimosaceae)
SB6	Flinders Rangewattle, crimson bottlebrush *Callistemon citrinus* (Myrtaceae), Howitt's wattle *Acacia howittii* (Fabaceae/Mimosaceae), Ovens wattle *Acacia pravissima* (Fabaceae/Mimosaceae), honey bracelet myrtle,
REM1	messmate *Eucalyptus oblique* (Myrtaceae), common heath *Epacris impressa* (Epacridaceae), Hazel *Pomaderris aspera* (Rhamnaceae), Clematis *Clematis aristata* (Ranunculaceae)
REM2	Messmate, common heath, Hazel,

days or 120 eggs in her lifetime. In addition to Trichogramma, there are about 26 other known parasitoids of eggs, caterpillars and pupae LBAM (Paull and Austin 2006) all of which will kill the host. We have found over 50 different parasitoids in surveys in vineyards throughout south eastern Australia, the role of all is not known but they include control agents of scale, mealybugs and even Rutherglen bugs and weevils.

Vegetation can support natural enemies and provide a source of pest control in the vineyard

The vineyard environment can be a bit hard on natural enemies, and adjacent vegetation provides reservoirs for new invasions, after winter when the canopy is returning or following the application of chemicals or other vineyard activities. By providing resources such as shelter, overwintering sites and food sources, adjacent vegetation can influence natural enemies present not only in the vegetation itself, but also in the vineyard. A number of natural enemies of LBAM, scale, mealybugs and pest mites are thought to benefit from food sources and shelter available in remnants and shelterbelts. These include parasitoids, lacewings, predatory mites, predatory bugs and spiders. At the same time, there are reports of vegetation increasing pests (Coventry *et al* 2004), so it is important to determine that there are no increases in pests associated with vegetation

Sampling with yellow sticky traps (in the canopy) and with pitfall traps (at ground level) at 8 sites at vineyards with adjacent remnant or shelterbelt vegetation in the Yarra Valley shows that a range of vegetation will increase a range of natural enemies both in the vine canopy and on the ground. We use the terms remnant and shelterbelt to refer to origin of vegetation: remnant vegetation was present prior to vineyard establishment and shelterbelt refers to vegetation planted subsequent to vineyard establishment but reference to the table listing vegetation at each site shows considerable overlap (Table 1).

We repeated sampling at both the shelterbelt (SB1) and remnant (REM1) margins of the vineyard reported in the earlier analysis (Thomson and Hoffmann, 2006a) and at 6 additional sites, with sampling points at the margin of the vegetation and in the vines 5m and 50m from adjacent shelterbelts (SB 2-6) and adjacent remnant vegetation (REM 2). Vegetation at each site is given in Table 1. Under-vine and inter-row management practices were similar: soil under the vines was bare earth following application of herbicides (Roundup and Basta®), and between the vines was mown grass. Only chemicals of low toxicity to beneficials (based on IOBC ratings - http://www.koppert.nl – and related data – see Thomson & Hoffmann 2006b) were used at all sites, including sulphur (Thiovit®) (at 200g/100L) and tebufenozide (Mimic®).

At each sampling point we placed a pitfall trap to sample invertebrates at ground level and a yellow sticky trap to sample canopy invertebrates. Pitfall traps consisted of an outer plastic sleeve, 22mm diameter x 150mm deep with a glass test tube 20mm diameter inserted so that the top of the trap was flush with the soil surface. The sticky traps were commercially available yellow sheets (240mm x 100mm) (Agrisense) which are sticky on both sides. These were suspended from the lower wire of a vertical two-wire trellis system so the lower margin was 1m above the ground. Sampling was repeated 4 times over 4 months (November-February).

Results show that vegetation adjacent to a vineyard influenced the abundance and distribution of natural enemies but also demonstrates the complexity of these effects. No site showed consistently high or low numbers of all groups. Vines adjacent to the vegetation had higher numbers of parasitoids, staphylinids and predatory thrips (at 8 of 8 sites), and spiders, Trichogramma and coccinellids (5 of 8) in the canopy assessed with yellow sticky traps and higher numbers of spiders, predatory mites and parasitoids at ground level assessed with pitfall traps (see Fig 2.). Changes in the relative abundance of beneficials extended well into the vineyards: for the parasitoids from pitfall traps, for instance, numbers were still higher 100m away from the shelterbelt. Similarly, for ground spiders, differences were detected 50m away from the remnant vegetation. These results suggest that vegetation can exert effects on numbers of natural enemies well away from the vegetation itself.

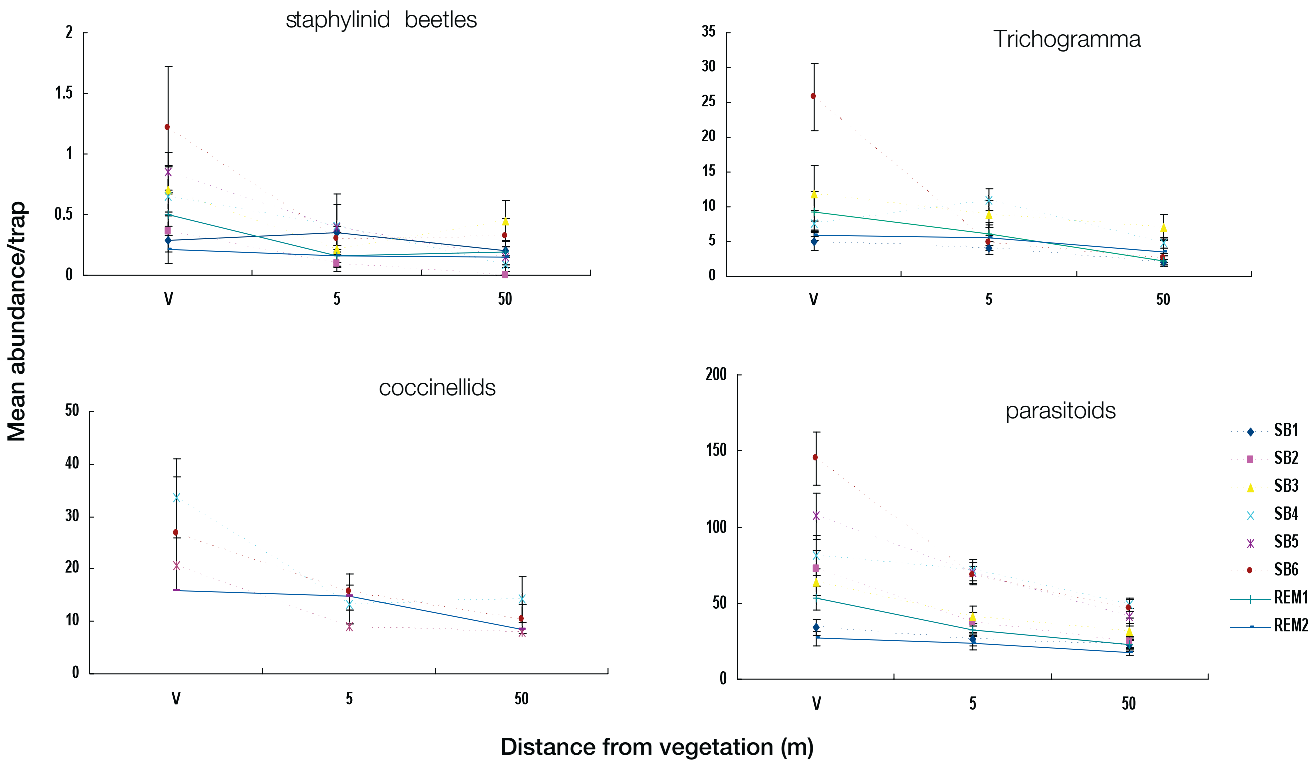

Fig. 2. Mean number of natural enemies for groups which decrease with distance: collected per trap with yellow sticky traps in the vegetation (V), at the vineyard edge (5m) and 50m into the vineyard. Solid lines represent sites with adjacent remnant and dashed lines adjacent shelterbelts. Error bars represent standard errors.

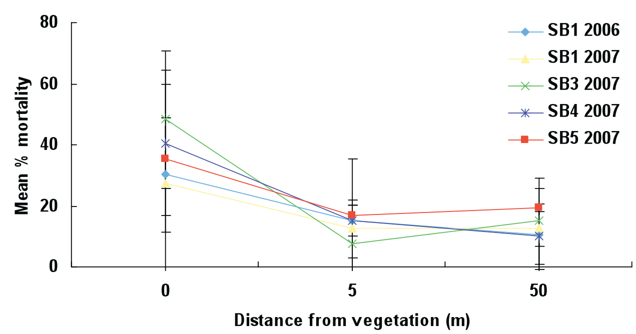

Fig. 3. The percent of lightbrown apple moth eggs taken by predators at the margin of the vegetation and in the vineyard canopy 5 m and 50 m from the vegetation at one site (SB1) in 2006 and 2007 and at 6 sites in 2007.

We also investigated natural predation of LBAM eggs so as to directly assess the impact of vegetation on pest control. We placed LBAM eggs, taken from our colony at University of Melbourne where LBAM lay eggs on plastic cups which are cut up to give a plastic card with 2-3 egg masses on each. Egg cards were placed at each of the 15 sampling points (5 vegetation, 5 each at 5m and 50m) at each of the 6 shelterbelt sites and were left for 5 days in the vine canopy and then collected. Cards were scored for missing egg masses and the percentage of egg masses lost to predation was calculated for each sampling point. On collection, 40% of egg masses were missing (assumed to be due to predation). Predation of eggs was positively associated with nearness to vegetation at 4 of the 6 shelterbelt sites (Figure 3). Predation of LBAM associated with the vegetation gives direct evidence for a positive effect of vegetation on LBAM control. The relatively higher predation rate near vegetation and positive correlation between predation and numbers of natural enemies suggests that high numbers of natural enemies have positive effects on pest control. On average, at sampling points close to the vegetation, the number of LBAM larvae would have been reduced from 1000 to 400 by the action of natural enemies.

The taxa increased by adjacent vegetation-predatory mites, spiders, staphylinids, lacewings, predatory flies (Tachinidae, Cecidomyiidae, Syrphidae) and a wide range of parasitoids including species of Trichogramma - all have a potential role as natural enemies in vineyards. In addition to their importance as generalist predators (see Michaels 2006), our collection of staphylinids included several species of Aleocharine staphylinids (genus Oligota) which are known to be predators of phytophagous mites (eg bud, blister and rust important in vineyards) (Paoletti and Lorenzoni, 1989). Spiders have wide host ranges (Memmott *et al*. 2000) allowing adaptation to fluctuations in host availability (Nyffeler *et al*. 1992) and they are likely to be predators of multivoltine pests like LBAM. Lacewings are voracious predators of mites, mealybugs and LBAM eggs. A multispecies complex of parasitoids such as that seen here can improve control of a range of pests (Rodriguez and Hawkins, 2000) and a range of parasitoids attack vineyard pests (Thomson & Hoffmann 2006a) including LBAM. Predatory mites contribute to control of eriophyoid mites, tachinids parasitise LBAM, some syrphids also eat caterpillars and may eat LBAM, Cecidomyiidae parasitise mealybugs and possibly scale (Waterhouse and Sands, 2001).

Vegetation in the vineyards tested here not only included many pollen and nectar producing plants, but were multistoried with grasses, shrubs and tall trees. Why did vegetation influence some groups? Vineyards can be recolonized from perennial habitats by the groups represented here: spiders, syrphids, staphylinids, parasitoids, predatory mites. Many spider species colonize crops by drifting through the air on threads of spider silk (ballooning), staphylinids possess a high movement rate (through flight or passive wind dispersal). Nectars are significant sources of nutrition for most adult predatory mites, lacewings, parasitoids, predatory and parasitic flies and staphylinids. Adjacent flowering plants have frequently been shown to increase natural enemies and biological control in a range of crops including vineyards (Williams and Martinson, 2000) and the results for LBAM egg cards reinforced the notion that increased control can occur adjacent to vegetation.

The shelterbelts and remnant stands had a range of vegetation but the common theme was complexity. Trees, shrubs and grasses support more abundant and diverse natural enemy populations. The data collected here suggests that existing vegetation and revegetation can contribute to pest control by natural enemies with the potential to reduce chemical applications, contributing to both increased economic and environmental sustainability in the viticulture industry. This work represents a step along the way to encourage environmentally sensitive and targeted crop protection measures. Complex vegetation can provide ecosystem services for a vineyard.

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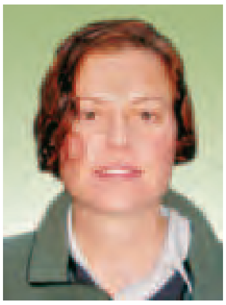

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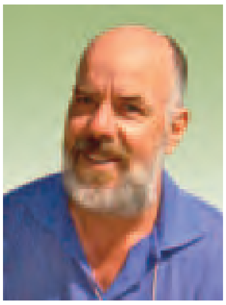

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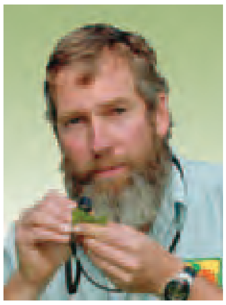

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Introduction

Integrated Pest Management (IPM) or Total System Approach[1] forms a substantial part of sustainable grape production, and has long been recognised as the only rational way to manage pests[2], because it usually results in significant reductions in pesticide use in the agricultural environment. For example, growers who produce 80% of Queensland citrus have achieved a 90% pesticide reduction (equivalent to an average annual savings of AUD$2 million over 2000ha of mature trees) in orchards where IPM is fully implemented [3,4]. Clear guidelines setting minimum standards for sustainable grape production were developed by the IOBC (International Organisation for Biological and Integrated Control)[5] (www.iobc.ch/IOBCGrapes.pdf). Other certification schemes for vineyards founded on IPM principles and practices have also been developed and adopted; for example, the Lodi Rules for Sustainable Winegrowing in California (Lodi Woodridge Wine Commission: www.lodirules.com) certified by Protected Harvest, Oregon LIVE (Low Input Viticulture and Enology: www.liveinc.org) certified by the IOBC, schemes in Switzerland (www.vitiswiss.ch), France (www.tyflo.org), South Africa (www.ipw.co.za), and Sustainable Winegrowing New Zealand (www.nzwine.com/swnz/). The Australasian Biological Control (ABC: www.goodbugs.org.au/IPMlogo.htm) certifies IPM-consultants and growers who implemented IPM, and trademarks IPM-accredited produce (including grapes) in Australia.

IPM gives priority to ecologically-based pest management methods and prevention, and aims to maximise the contribution of biological control to overall pest control. To this end, it harmonises pest control methods (cultural, chemical, biological, ecological engineering) to prevent one control cancelling out the benefits of another. For example, by avoiding situations where a fungicide achieves control of a pathogen, yet is highly toxic to predatory mites and disrupts the natural biological control of a pest. This was the case where mancozeb killed predatory mites in Australian vineyards [6,7]. Pesticides are chosen to minimise toxicity to naturally occurring bio-control agents. By using IPM, growers can achieve the required crop quality and yield, while reducing farming inputs, and environmental and human health risks. To appreciate the potential of IPM, it is worth noting that the majority of all potential crop pests are controlled biologically[8], and that this "free-of-charge" ecosystem service is conservatively estimated to contribute US$100 billion to the world economy each year[9,10].

To build healthy thriving populations of vineyard predators and parasitoids[11-13], and to enhance the service they provide, a range of steps can be adopted, progressively moving from simple to fully integrated IPM. Here we provide a technical summary of wine grape IPM. We list steps I-V along the IPM-adoption spectrum, and give control options for each pest and disease (Tables 1-8) for growers to refer to when evaluating their IPM adoption, and choosing the next feasible step. Most potential vineyard pests in Australia are listed, but none requires regular annual treatment in IPM vineyards, and practically no vineyard has all of these pests. This is thus a reference manual, and growers need not be familiar with contents of all tables in order to begin IPM of the key pests (Tables 1-2). We anticipate it will serve as a technical reference and a starting point for a practical, sustainable wine grape production certification scheme in Australia. We hope innovative industry leaders will use it to realise environmental, cost saving, and marketing benefits from genuinely sustainably-produced grapes and wine.

Stepwise guide to IPM adoption

Practical IPM adoption is a range of steps, which progressively moves the vineyard to more integrated, lower input production. Over time, we reduce our reliance on insecticides as the main means of pest control, and reduce pesticides to minimum requirements. Naturally occurring bio-control agents are a "free service" provided by the ecosystem; this service improves with each year of adoption.

Step I: Minimise sprays that are toxic to beneficials, and monitor pests and diseases

The first step is to minimise the use of insecticides and fungicides toxic to natural enemies of pests. As a result, sprays applied for one pest/disease do not lead to pesticide-induced outbreaks of another pest, and the cost of such secondary outbreaks is eliminated. To achieve this we need to:

(a) use insecticides that cause as little damage to natural enemies as possible, instead of toxic broad-spectrum sprays[7,14-16]

(b) substitute safer fungicides for more toxic ones registered for the same target disease[6,7]

(c) monitor pests, and use insecticides only at key times when monitoring indicates a spray is economically justified.

For example, for chemical control of lightbrown apple moth (LBAM, *Epiphyas postvittana*) this means using tebufenozide (e.g. Mimic 700 WP) or BT (*Bacillus thuringiensis*) formulations (e.g. Dipel DF) in place of other registered products, where possible (Table 1). Further laboratory testing of novel LBAM insecticides and validating results in the field on key Australian and New Zealand natural enemies is needed, but at present, it is wise to use safer, effective alternatives where possible. Newly registered high label rates of wettable sulphur also require such testing. It is especially important to minimise toxic sprays early in the season, as damage to bio-control at this time has the most significant consequences, which may last for the rest of the season. Cultural controls such as increasing canopy aeration, and infection period or monitoring-based (rather than calendar-based) fungicide use are also important here, because they generally result in reduced spray frequency and lower overall toxic exposure of natural enemies. At present, Step I pest and disease monitoring is offered by chemical re-sellers, independent viticulture consultants, and Cropwatch® in some regions, but systematic reduction of pesticides toxic to beneficials and bio-control integration can be variable, and often limited.

Step II: Step I and monitor beneficials

Pests and beneficials are monitored every 7-10 days over the growing season. Results are used to decide when to spray, and when not to spray. This often leads to significant reduction in insecticide use. Insecticides play a valuable support role, but by Step II this is more defined and targeted: pest control is achieved by natural bio-control as far as possible, and insecticides only assist in reducing pest numbers, by regulating pest populations down to levels where beneficials can again take over and maintain pests below economic damage. Insecticides are spot-sprayed where applicable. Pest and beneficial monitoring and guidance in full IPM-adoption are at present generally offered only by IPM specialists (www.goodbugs.org.au/suppliers.htm). Vineyards receive Step II monitoring service, data interpretation, advice on all aspects of IPM adoption, and successfully prevent (and cure) mealybug, weevil, and mite outbreaks. But these services have a limited capacity, and the Australian wine industry and other horticultural sectors face a skills shortage in this area at present. Monitoring can be done by growers, employees, or external services, but adequate training must be undertaken and time allocated to carry out monitoring at set intervals over the season[14]. Where pest control requires decisions on ≥2 pests and their associated beneficials, it is estimated that two-year full-time on-the-job specialist training is needed for full IPM proficiency and data interpretation (D. Papacek, pers.com). Growers may therefore benefit by employing an IPM service. Disease/pest/beneficial monitoring is ideally combined into one service. Commercial IPM pest and beneficial monitoring is outlined in Tables 1-2, and pest species-specific methods (Tables 1-7).

- **Spray thresholds.** Meaningful action thresholds for most pests and beneficials cannot be set at present, because they are subject to complex interactions involving many species and factors that vary between vineyards, seasons, and years. To compensate, spray thresholds tend to be set very low, disregard beneficials, and have little meaning in vineyards where bio-control is utilised. Sound thresholds that incorporate natural enemies are beyond the scope of simple linear mathematical models currently available, but may be accurately estimated by mathematical algorithms in the future. At present, interpretation of pest and beneficial monitoring data therefore relies on site and region-specific expert IPM knowledge, data collection (including life-stages) every 7-10 days over the growing season, and past monitoring records.

Step III: Steps I-II and encourage beneficials inside the vineyard

Beneficial insects and predatory mites can be encouraged by inter-row and under vine management. The emphasis is on providing a supplementary food source in the form of high quality, easily accessible nectar and pollen, shelter from summer heat and low humidity, and over-wintering habitats. Steps II-III may be adopted at the same time, but Step III should only be used once Step I is fully implemented.

- **Alternate row mowing** (allowing grass swards to flower) provides pollen for predatory mites[17], and habitat/shelter for insect predators and spiders living and reproducing in long grass, such as brown lacewings and damsel bugs[11], but its use can be limited by frost or drought.
- **Under-vine mulching** (composted/fermented marc, shredded office paper, or mowing grass with side-throw slashers to place grass under vines) reduces water evaporation and runoff, improves soil structure and water-holding capacity, and increases soil microbial activity. Latest research also shows that mulching breaks *Botrytis cinerea* life cycle by soil microbial activity, while the pathogen over-winters on the vineyard floor, leading to significant reductions in *B. cinerea* primary inoculum and bunch infections the following season[18-20]. Results of a three-year study in Australia also indicated that some composted marc formulations were associated with reduced phylloxera populations emerging above-ground, and hence reduced quarantine risks[21]. However, green waste was associated with increased phylloxera emergence[22] and further research is needed before making recommendations on phylloxera management and mulching.
- **Providing nectar for beneficials.** In some New Zealand vineyards, flowering buckwheat (*Polygonum fagopyrum*) in every 10th mid-row (25m) reduced LBAM and other leafrollers below economic thresholds without a need to spray (Table 1; AgNote: www.phylloxera.com.au), by providing supplementary food for a parasitoid wasp of LBAM larvae (*Dolichogenidea tasmanica*); the most abundant LBAM parasitoid found in Australian and New Zealand vineyards to date[12,13,23,24]. Buckwheat nectar significantly increased *D. tasmanica* lifespan, egg load, and parasitism compared to water controls in extensive New Zealand studies[25-30]. The spacing was carefully worked out by rubidium-marking nectar-feeding wasps and studying their movement, and abundance away from the nectar source[31]. Parasitoids of mealybugs and scale insects, and some predators whose adult stages feed on nectar (e.g. hoverflies, green lacewing-*Mallada signatus*) may also be enhanced. Sugar composition of nectar determines its utility to beneficials, and only nectars with specific sugar-signatures are proving suitable. Besides buckwheat, Phacelia (*Phacelia tanacetofolia*) has suitable nectar, but its utility is not as high as that of buckwheat, and latest Australian research ▸

identified white alyssum (*Lobularia maritima*) as a valuable nectar source for *Trichogramma carverae*[32].

- **Australian native plants as a source of nectar.** The promising nectar potential of native plants is being studied in New Zealand, and needs to be studied in Australia. Combining Landcare and Greening Australia re-vegetation projects with research on enhancement of key beneficial species could provide significant benefits to growers. Future measures may include native windbreak, headland, erosion and salinity control plantings with nectar and pollen utility to beneficials. But pollen, nectar and other plant features must not enhance pests. Future research on relative benefits of native flowers must therefore carefully screen this. Some Australian native pests (e.g. LBAM, vine moth, vine weevil) would almost certainly be favored by some native plant species.

Step IV: Steps I-III and release beneficials (if required)

Further benefit may be achieved in some vineyards by augmenting low numbers of key beneficials by releases. This is most likely to be effective where releases are made in the early stages of pest infestation (or even preventatively) into crops which have a history of recurrent problems with a particular pest. For example, in Australia releases achieved significant control of mealybugs in table grapes (using *Mallada signatus*), of scales in citrus (using parasitic wasps), heliothis (*Helicoverpa*) caterpillars in corn and macadamia nut borer in macadamia (using *Trichogramma sp.*), and pest mite control in strawberries and glasshouse crops (using predatory mites *Phytoseiulus persimilis* or *Galendromus occidentalis*). In many vineyards however, Step IV may not be needed at all, and where releases are made they are often not needed on ongoing basis. Only a few species are available for release, successful vineyard and orchard IPM thus relies, in the first instance, on systematic enhancement of naturally present species (Steps I-III). Step IV is recommended only when required, based on monitoring and IPM-specialist advice once Steps I-III are adopted, or to introduce a key beneficial species absent from a vineyard or a region, or in other crops (such as citrus), for short 4-6 week periods to achieve high levels of parasitism at key times. Latest research clearly shows increased longevity and parasitism by wasps parasitising LBAM (*D. tasmanica* and *T. carverae*) when they have access to specific nectar. Therefore it may be prudent to provide such a nectar source in vineyards prior to considering release, firstly for naturally present wasps, and secondly to maximise the benefits of potential releases.

Step V: Steps I-IV and encourage beneficials at a regional level

This step consists of improving the wider landscape in order to ▸

Table 1. Options for LBAM and VINE MOTH management (IPM-compatible; text in blue IPM-transition; text in red IPM- incompatible)

IPM monitoring method (suitable for commercial monitoring) of pests, beneficial insects, and spiders in the vine canopy:
Weekly monitoring of whole vine shoots by direct observation: scan shoots from tips to base, both sides of leaves, and a 10cm cordon section below each shoot. This method was chosen for its utility to pests (LBAM and vine moth larvae and eggs), and key beneficials (green lacewing activity is best sampled by egg counts [35, 36]). It can be used together with **canopy checks using beating trays (using large cloth or plastic funnels)** to best sample predator larvae, spiders, and some predatory mites. The strength of monitoring is in the ability to compare results week to week and season to season, and in a fast response to infestations (within a time it takes LBAM eggs and mealybugs to develop into early instars). 14-day monitoring of vine canopy is usually not recommended, as it results in up to 3-wk delay in response to infestations. Where alternate row mowing is practiced, growers can **check beneficials in long grass mid-rows by suction sampling** randomly chosen 1m^2 units of long grass (for ≥ 60 sec), using a reverse vacuum suction leaf-blower every two weeks. The suction tube is fitted with a nylon bag to collect the catch. Catch is examined in a large white tray, and immobilised with a fine spray of water. It is not commercially viable to monitor every block in great detail. Monitoring thus relies on the assumption that random examination of a limited number of shoots corresponds to overall vineyard situation. Where pesticides toxic to beneficials are used, many patchy pest flares can develop, and uniformity cannot be assumed. Success and reliability of commercially viable IPM monitoring thus depend on implementing Step I, and on expert data interpretation.

	Monitoring	Chemical control	Bio-control Naturally present	Cultural control Ecological engineering	Bio-control for release
LBAM Lightbrown apple moth *Epiphyas postvittana* **Other leafroller species**	**Weekly monitoring of larvae, scanning 100 shoot-replicates from tip to base, is used to decide if to spray.** Egg-masses are also scored, but are not the main target, because the highest mortality occurs at egg-stage and 1st instar larva and egg-mass counts seldom correspond to larvae in the vine canopy [38, 39] (Bernard, Horne unpublished data). Delta traps may be used to indicate adult flights, but not to decide when to spray, as peaks in male numbers in traps do not correspond to peaks in larvae, or damage at harvest [23] (Bernard, Horne, unpublished data). **Infrequent (≤ fortnightly) monitoring;** quick checks only; monitoring of LBAM egg-masses only. **Monitoring LBAM by delta traps and pheromone lures; using male counts to decide when to spray.** This results in unnecessary insecticide use, as male trap counts can be very high (esp. early in the season), even though canopy larval infestations are negligible. These unnecessary early season sprays can damage beneficials, found in high numbers at this time [11]. **Broadcasts of 'regional LBAM alerts' used to decide when to spray.** This disregards the large variations in LBAM larvae in vines from vineyard to vineyard, and leads to unnecessary spray use.	**Tebufenozide (e.g. Mimic 700 WP), and BT (*Bacillus thuringiensis*) formulations (e.g. Dipel DF) are used based on monitoring, in preference to other insecticides. Spray diary minimises use of sprays toxic to beneficials.** **Indoxacarb (e.g. Avatar®), emamectin (e.g. Proclaim®), spinosad (e.g. Entrust Naturalyte®) may be used within an IPM strategy.** But each kills some beneficial species, and so the decision on which to use and when is based on monitoring of beneficial species and numbers (i.e. spinosad is quite safe to many predatory species, but is harmful to parasitoid wasps, causing direct mortality and sub-lethal effects such as reduced longevity and egg-lay; indoxacarb is toxic to both a key predator, the green lacewing (*Mallada signatus*),and a key LBAM parasitoid (***Dolichogenidea*** *tasmanica*) [15, 40]. **These insecticides are thus used only when high pest numbers are present outside the tebufenozide spray window.** **Calendar-based use of any of the above insecticides regardless of pest and beneficial numbers. Use of carbaryl** (e.g. Carbaryl 500) **or chlorpyrifos** (e.g. Lorsban 500 EC) **in place of any of the above insecticides.**	**Parasitoids of LBAM** see [12], were extensively evaluated in Australia (Limestone Coast) only recently by University of Adelaide [13], and in a smaller study by the authors (Yarra Valley) [12]; most common parasitoid to date is ***D. tasmanica***, but many species make up the beneficial complex of LBAM, including parasitoids of larvae, and parasitoids of eggs *(Trichogramma sp).* **Generalist predators** feeding on LBAM see [11].	**Weed-free grass swards reduce LBAM host plants.** **Alternate row mowing** allows grass to flower in every 2nd row to provide pollen food source, and shelter from heat and low humidity for beneficials. **Flowering buckwheat strips (1 in every 10 rows)** provide high quality nectar for parasitoids, and for predators whose adult life stages feed on nectar and pollen (studied on *D. tasmanica* at Lincoln Uni, New Zealand [25-30]), and reduced LBAM damage below economic thresholds in some New Zealand vineyards, without a need to spray. Other nectar resource plants evaluated on LBAM parasitoids are: Phacelia (*P. tanacetifolia*), and white alyssum (*Lobularia maritima*) [32]. **Use nectar resources only once IPM Step I is implemented.**	*Tricho-gramma carverae* [14, 37] Release only if naturally present bio-control enhanced by nectar resources is not able to achieve control.
Grapevine moth *Phalaenoides glycinae*	A pest of minor economic importance (causing occasional leaf damage in young vines). It has a very high fecundity but is generally successfully controlled by naturally present bio-control agents [41], except if present in high numbers near harvest. Presence in harvest bins can lead to down-grading of crops by wineries, but BT sprays prior to harvest are very effective. Monitoring and sprays as above.		Overview of natural enemies and photos [11, 12, 41].		No need to release

Table 2. Options for MEALYBUG management (IPM-compatible; text in blue IPM-transition; text in red IPM-incompatible)

Alternative 1: Bio-control and minimal insecticide use

Mealybug outbreaks in wine grapes in Australia are only very recent (*c.* from 2000-01), yet the pest (longtail mealybug) is considered native to Australia, and has been found in very low numbers in vineyards without causing economic damage for many years (controlled by beneficials). By contrast, it has been a major pest in table grapes for many decades, where bio-control is disrupted by frequent use of many broad-spectrum insecticides. Number of sprays can exceed 5-10 per season, often without achieving control. Yet some table grape growers successfully practice IPM, reducing their insecticide use against mealybug to 0-(2) sprays of buprofezin (e.g. Applaud®) per season, repeatedly showing that mealybugs can be successfully controlled by:

(1) Relying on natural bio-control as far as is possible from early Spring into the season
(2) Controlling ant species that interfere with bio-control by an IPM-compatible method (Papacek; Horne & Kourmouzis; Altmann & Weppler, unpublished data).
(3) Monitoring mealybugs and beneficials throughout the growing season, and spraying only if required late in the season, when beneficial numbers decline.

Alternative II: Insecticides as the sole means of control

Outbreaks of longtail mealybug (e.g. in WA vineyards) can have severe economic effects (direct damage, crop rejection due to sooty mould wine taint, and vine collapse due to vine leaf-roll virus transmitted by 1-2 instar longtail mealybugs [42]). As a result some growers and their advisers quickly reach for broad-spectrum insecticides; often from early in the season and for only minor infestations. Broad spectrum insecticides are also used as a butt-drench in WA, in an attempt to control weevils. In these ways, the best window of opportunity for bio-control (when mealybug numbers are low) is lost. Bio-control agents are killed by insecticides, and growers become locked into repeated pesticide use. Mealybug numbers increase quickly in the absence of beneficials and several sprays may be used by capfall. Even where mealybug control is achieved this way, it can be quickly lost soon after capfall, as no insecticides against mealybugs are registered for use in wine grapes after 80% capfall. Growers then face the dual problem of having **(a) no sprays available against mealybug, and (b) no natural bio-control left.**
As a result, mealybug numbers often soar at *c.* mid March (e.g. Pinot Noir harvest), and crops may be rejected. This in turn prompts pre-budburst, and early season applications of broad-spectrum insecticides the next Spring, and the pesticide treadmill is repeated. Other pest outbreaks can follow: rust mite, two spotted mite (TSM), or even other tetranychid mites as recently reported from WA (Table 4). Chances of vine leaf-roll virus transmission by mealybugs increase with the severity of ongoing infestations; vine collapse can eventually result (recently reported from WA and Hawke's Bay, NZ). Ongoing insecticide use also increases the chances of exceeding MRLs. This scenario is completely environmentally and economically unsustainable. Yet, the initial per ha cost of broad-spectrum insecticides is low and often prompts their use.

	Monitoring	Chemical control	Bio-control Naturally present	Cultural control Eco- engineering	Bio-control for release
Longtail mealybug *Pseudococcus longispinus* (main pest) **Citrophilous mealybug** *P. calceorariae* (less common) **Obscure mealybug** *P. viburni* (only in QLD)	Mealybug distribution is usually clustered unless large infestations occurred for several years. Monitor pest and beneficials as (Table 1). **Mealybug-specific methods** **(1)** Weekly checks of sheltered leaves at vine crowns on both sides of leaves [43], 4-5 leaves per vine crown, *c.*30 randomly chosen vines. (2) If mealybug is found, tag vines and check weekly to evaluate changes in pest numbers, development, and presence of beneficials. (Many green lacewing eggs and larvae are found on mealybug-infested vines in IPM-vineyards). Use of pheromones is in development in the USA and New Zealand.	**(1) Reliance on natural bio-control from early spring as far as possible, based on monitoring** (this is usually possible for the entire season under IPM, sometimes a spray may be needed) **(2) Targeted spot-baiting of honeydew-feeding ants (not all ant species!) that protect mealybugs from predation and parasitism, based on monitoring (see also Table 3).** Baits, sticky bands, or baited spot chemical treatments are widely used by IPM specialists in many crops to improve bio-control. **(3) Buprofezin (e.g. Applaud®) timed to emergence of high crawler numbers; after steps 1-2 and if monitoring indicates spray is needed (beneficial numbers are low and unable to contain the pest).** This is best done based on expert long-term experience, in consultation with IPM specialists. **(4) Dormant winter oil spray** (e.g. Biopest) (based on monitoring and IPM specialist advice), if pest numbers were high late the previous season and steps (1-2) did not achieve control (see also Table 3). **Buprofezin (e.g. Applaud®) used on calendar basis.** **Broad-spectrum insecticides such as methidathion Warning! S7 Poison** (e.g. Suprathion 400 EC) **and maldison** (e.g. Maldison 500), or other registered products **timed to crawler emergence or on calendar basis, including as spot-sprays.**	**Parasitoids** - many species are recorded from Australia; some were exported to USA, Israel, New Zealand, earlier in 20th century. Despite this, a quantitative evaluation of the parasitoid species complex has never been done in Australia, nor has field predation been quantitatively evaluated. Both are needed to solve recent major outbreaks. **Predators** noted feeding on mealybugs: green and brown lacewings (*Mallada signatus; Micromus tasmaniae*).	**Alternate row mowing** creates habitat for predators and parasitoids. **Flowering buckwheat, Phacelia** as per (Table 1) may also enhance parasitoids of mealybug and vine scale, and nectar feeding adult life stages of key predators e.g. *M. signatus*, by the same mechanisms that enhance LBAM parasitoids. But to date nectar evaluation on parasitoids of mealybugs or scale has not been done in Australia. Such research has a great potential to aid mealybug control and prevention.	**Green lacewing** *M. signatus* (not found in New Zealand); The citrus mealybug predator *Cryptolaemus mountrouzieri* [14, 44] is available, but release results in vineyards to date have been variable and differed in regions, suggesting a possible preference for citrus (see also Table 3).

NOTE: Buprofezin and methidathion are registered only against longtail mealybug.

Table 3. Options for management of SCALE (IPM-compatible; text in blue IPM-transition; text in red IPM-incompatible)

Soft Scales	Monitoring	Chemical control	Bio-control Naturally present	Cultural control Ecological engineering	Bio-control for release
Grapevine scale *Parthenolecanium persicae* **Frosted scale** *Parthenolecanium pruinosum* **Other species rarely found in vineyards** *Coccus hesperidum* *Parasaissetia nigra* *Saissetia oleae*	**Grapevine scale**. This species is relatively common, it occurs in clumps, difficult to detect at low densities. Infested vines usually have ants moving up the trunk, and scales are best detected by looking for ant activity. Leaves or bark on infested vines may glisten with honeydew, or be black with sooty mould. One generation occurs per year. Scales mature in Spring, becoming very convex, brown to reddish-brown, and are usually found near the bases of canes and under the bark of cordons. Cream eggs are deposited under adult females October - November. Crawlers (≤ 0.5mm) hatch *c.* early November. Crawler emergence can be monitored using double-sided sticky bands on canes above adult infestations. Clear to yellow crawlers (darkened with age) are found on underside of leaves in Summer, along leaf veins (inspect with 20x magnification). They move from leaves to canes and older wood in Autumn, to over-winter. **Frosted scale.** New research indicates this species is more common in vineyards, than is generally assumed (Rakimov, unpublished data). Lifecycle and monitoring as per grapevine scale. Immature life stages are similar in appearance to grapevine scale. Eggs are white, and adults are covered in a white waxy powder. **Other species.** These are rare in vineyards, but can be common in other crops. Their biology has been worked out for other crops such as citrus and olives, but may vary in vineyards. Monitoring (as above)	**Enhancing naturally occurring bio-control by minimal use of sprays toxic to beneficials.** <u>Spot-baiting</u> **(not broad-scale use of bait) of ant species that protect scales from natural enemies (Table 2) can improve bio-control of scale.** Target only ants that tend scales and harvest honeydew, by applying minute amounts of bait mixed with insecticide to vines where ant tending is observed. No insecticides are registered as baits in grapes in Australia, and many ant species are beneficial, so baiting must be absolutely minimal and precisely targeted. Baits, sticky bands, barrier glue, or baited spot chemical treatments are widely use by IPM specialists in many crops to limit ant access to honeydew-producing pests and improve bio-control [44]. **Spot-spraying clumped infestations with summer oil**, if beneficials and baiting alone did not achieve control, and scale numbers are high. Tag scale clusters and monitor crawler emergence to time sprays, targeting undersides of canes and cordons where most scales are found. Pruning prior to sprays can increase spray coverage. Summer oils are phytotoxic to vines, and care must be taken to avoid vine damage. **Spot-spraying infested vines with winter oil (e.g. Bioclear) at dormancy.** Winter oils are phytotoxic to vines and can only be used during full dormancy. **Spot-spraying broad-spectrum insecticides** such as methidathion Warning! S7 Poison (e.g. Suprathion 400 EC), maldison (e.g. Maldison 500) optimally timed to crawler emergence (based on monitoring) if beneficial numbers are low, can reduce crawler numbers. Tag scale clusters and monitor crawler emergence to time sprays. **Broad-scale use of the above insecticides** over whole vine block/s at crawler emergence, or on a calendar basis, or as dormant sprays. Broad-scale use of chlorpyrifos (e.g. Cyren 500 EC) or chlorpyrifos/ winter oil mixture in dormant vines. Only some chlorpyrifos products are registered for use in dormant vines and only against grapevine scale.	Evaluation of the beneficial species complex is underway GWRDC Project DNR03/01. **Parasitoids.** Some six species of parasitoid wasps are recorded from *P. persicae* in Australia so far, *Metaphycus maculipennis* and *Coccophagus lycimnia* appear to be the most important (Rakimov, unpublished data). **Predators.** Ladybird beetles, including *Cryptolaemus montrouzieri*, and caterpillars of a predatory moth *Mataeomera dubia* are important predators [46, 47], but may not be naturally present in some regions. Larvae of the green lacewing (*Mallada signatus*) and brown lacewing (*Micromus tasmaniae*) feed on soft scale eggs and crawlers [44]; both species are common throughout Australia. Other ladybird beetles also feed on scales [44], including *Rhizobius* sp. Predatory whirli-gig mite (*Anystis baccarum*; 1 -1.5 mm in size) abundant in Limestone Coast and King Valley vineyards and present elsewhere, was also noted to feed on eggs and crawlers.	**Pruning** Pruning can remove many scales from the vine, and minimal pruning can favor population increase. Pruning prior to dormant spray application [45] helps increase spray coverage. Consider mulching cane prunings, to kill scales which may otherwise move back onto vines. **Alternate row mowing** is a practice known to provide shelter and pollen for beneficials. **Provision of high quality nectar** for beneficials using buckwheat or phacelia (Tables 2-3) is expected to also aid scale parasitoids, but research specific to these wasps has not yet been done. **Moderating nitrogen fertilizer and irrigation** if infestations are high, may reduce scale population growth.	**Green lacewing** *Mallada signatus* (as above) **Ladybirds:** *C. montrou-zieri* [14]; netting with nylon cloth over release spots for 2 weeks after release may improve bio-control, but this does not necessarily lead to establish-ment in vineyards.

enhance biological control. Such initiatives follow on from long-term overseas studies (e.g. on lacewings and parasitoids) and their movements, and are undertaken in recognition of the large spatial scale on which populations of many pests and beneficials operate. Overseas studies show that native vegetation reserves, including roadside verges and headlands are a source of beneficials, and that generally, the more complex the landscape and the larger the vegetation remnant, the higher the utility to bio-control[33,34]. To best aid natural bio-control, regional landscape modifications need be based on research and give specific benefits to key beneficials. One such region-wide ecological restoration scheme is underway in New Zealand (using Steps I-V) (www.waiparawine.co.nz/index.cfm/research/greening_waipara.html, www.lincoln.ac.nz/story13772.html). It aims to provide environmental, cost saving and marketing benefits to growers, and help differentiate the region in domestic and international wine markets.

Limitations of this guide

This guide is not intended as a complete account of control and monitoring practices. For further information see references provided, contact the authors, or IPM specialists in your area. For pesticides, always read labels (http://services.apvma.gov.au/PubcrisWebClient/welcome.do), check withholding periods and MRL requirements (www.awri.com.au), and consult the winery prior to use. Management of mollusks such as the brown garden snail (*Helix aspersa*), small pointed snails (*Cochlicella barbara*), and minor localised occasional insect pests (e.g. common auger, spring, or fig longicorn beetles), is not included; consult IPM specialists in your area. Disease management in viticulture to date combines cultural controls with calendar-based or infection period-based fungicide use. These practices are summarised here, but growers should consult detailed management information and disease monitoring details elsewhere. With the exception of Botrytis, IPM presented here only seeks to modify fungicide use by substituting sprays toxic to beneficial insects and mites, with safer products. But disease management using natural grapevine defenses, and antagonistic micro-organisms (Table 8), is a key future step in IPM. Herbicide reduction occurs via under-vine and mid-row management methods listed here, but it is not otherwise addressed. Pesticide safety to humans is also not addressed. This guide is subject to limitations in current knowledge (mid-2006) on pesticide safety to native Australian beneficial species outlined below, and may change when new rigorous Australian data become publicly available.

Limitations - pesticide safety to beneficial invertebrates

Most data on pesticide safety to beneficials are not generated on Australian species, and extrapolating from one beneficial species to another is not reliable. The Australian regulator (APVMA) requires no data on beneficial invertebrate safety (except for honeybees and earthworms) for pesticide registration, and sets no other

Table 4. Options for management of MITE PESTS (IPM-compatible; text in blue IPM-transition; text in red IPM-incompatible)

	Monitoring	Chemical control	Bio-control Naturally present	Cultural control Ecological engineering	Bio-control available for release
Rust mite *Calepitrimerus vitis* **Restricted Spring Growth (RSG) due to rust mite**	**To diagnose presence: Early spring rust mite damage is also called RSG due to rust mite in Australia,** for details and photos see [54-56]; rust mite and bud mite are the only proven causal agents of RSG to date [56]. Record spring damage when it is most pronounced: up to *c.*5-8 separated leaves. **Late summer damage:** Record severity of leaf bronzing (mid January to early March). If bronzing is moderate to severe spraying at woolly bud the next Spring will prevent RSG due to rust mite. If no/very low bronzing, there is no need to spray. This is reliable unless predatory mites were disrupted late in the season. **Species ID:** D. Knihinicki (DPI NSW-Yanco), or DPI Knoxfield).	**Minimise use of sprays toxic to predatory mites to achieve a lasting prevention of all pest mite outbreaks, without the need to spray each year [6, 56].** **If a spray is needed against rust mite (i.e. leaf bronzing occurred the previous season), 'woolly bud spray' timed to rust mite migration from winter shelters is used.** Wettable sulphur (e.g. Thiovit Jet) is effective, IF spray volume saturates thick bark of vine cordons. For precise spray requirements, windows for different vine varieties, and other options see [54, 57]. Temperature ≥ 15 °C during spraying improves wettable sulphur action [58]. **Annual 'woolly bud' spray** regardless of bronzing damage **Late season and post-harvest WS sprays** have little effect; over-wintering females are protected from c.late January[59] **Lime sulphur at dormancy:** is highly toxic to most beneficials and can compromise IPM for the entire season.	**Predatory mites** (Acari: Phytoseiidae) provide long-term preventative control of rust mite, bud mite, and other mite pests. Key species in Australian vineyards: *Typhlodromus dossei, T. doreenae, Euseius victoriensis, Galendromus occidentalis* [48-50], (Bernard, unpublished data) **Predatory thrips** *Haplothrips victoriensis* also feeds on rust mite and TSM [11, 51].	**Alternate row mowing** provides grass pollen as a supplementary food source for predatory mites [12, 17] **Nursery stock** hot water treatment of dormant cuttings (52°C for 60 min) eliminates rust and bud mites [52] **Infested, pruned canes** do not lead to rust mite re-infesting vines the following Spring [53]	*E. victoriensis G. occidentalis* Only release where predatory mites at *c.* flowering are absent/ very low. Assess naturally present numbers prior to release on ≥ 4 x 25 randomly collected leaves; by counting under microscope (6-12x magnification), or scoring % leaves with predatory mites. /OR Release without prior assessment if broad-spectrum pesticides were used in previous years.
Bud mite *Colomerus vitis* **RSG due to bud mite**	**To diagnose presence:** **(i)** Locate clustered damage spots and tag; damage photos see [49], [56]-contact authors for a copy. **(ii)** Collect healthy-looking un-burst buds (normal-looking buds as if in bud-swell) soon after node-1 bud burst and up to *c.* mid-late October. Do not collect damaged buds with bleached, exposed hairs. These are long-dead, rotten inside and past the point when the cause can be diagnosed [56]. **(iii)** Species ID: D. Knihinicki (DPI NSW-Yanco, DPI Knoxfield).	**Wettable sulphur spray (no oil!) immediately after node-1 bud-burst (at node-2 rosette, 1-2 wks after node-2 burst)** [55, 60]. Diagnose bud mite prior to spraying and do not spray on routine annual basis. Spray volume to run-off, *c.*0.5 L per vine is suggested by [61]. Reduced damage symptoms will not be evident until next Spring, because damage was caused before sprays were applied. 'Woolly bud' spray against rust mite does not work against bud mite, as bud mite (unlike rust mite) is protected deep inside buds at woolly bud. **Lime sulphur** (as above), and no effect on bud mite (Hurst & Hoffmann, unpublished data), which is deep inside winter buds.			
Two-spotted mite (TSM) *Tetranychus urticae*	**To diagnose presence:** **(i)** Locate damage symptoms by fast scanning upper leaf blades first; once damage symptoms are found, confirm infestation on the underside of leaf by examination through at least a 10x hand-lens, and **(ii)** confirm species ID. Examine leaves for presence of predators at the same time.	Not common in wine grapes in Australia. But where it is present very major economic damage can occur, if vineyard is not IPM-managed. Outbreaks indicate disruption of natural predators [17, 62-66]. Currently where resistant populations occur, only two pesticides are effective against TSM, both are extremely expensive and not registered in wine grapes in Australia.	**Black ladybird beetles** ***Stethorus*** sp. [11, 67], *G. occidentalis* is naturalised in some vineyards, *H. victoriensis*	Alternate row mowing (as above)	*G. occidentalis* Release usually not required in IPM vineyards in Australia.
Six-spotted mite *Eotetranychus sexmaculatus*	A new pest in WA vineyards (same family as TSM) native to America first recorded in WA in 1986 [68]. Diagnose presence (as above).	Little known in vineyards, but recorded in WA orchards. It is worth establishing whether it has been induced by broad-spectrum sprays used in WA for the control of other pests.	Predatory groups (as above) but native species of predatory mites in WA vineyards are yet to be identified, and are likely to be different to the eastern States.		
Bunch mite *Brevipalpus lewisi*	**To diagnose presence:** slightly raised black spots at base of canes can be visible from November if infestations are high; dark brown scaring forms later on bunch and berry stems, berries may shrivel and fall [69]. Confirm species ID: D. Knihinicki (DPI NSW, Yanco), or DPI Victoria, Knoxfield).	Minor pest in wine grapes in Australia; sprays usually not required in IPM vineyards in Australia	(as above)	Alternate row mowing (as above)	Release usually not required (as above)
Leaf blister mite *Colomerus vitis*	This species is in the process of being renamed, based on molecular work which separated it into a distinct species from that of bud mite [70]. Practically, this means that it is not associated with the damage caused by bud mite, its damage (blister-like erinea on leaves) is cosmetic, and not economically significant. Natural enemies (as above).				

testing standards. Data on Australian beneficials are thus few, and obtained from tests of varying methodology and rigor. Moreover, data generated by pesticide manufacturers are usually marketed in Australia in promotional material, without the disclosure of testing methods. This information is difficult to interpret, because it is a well-established fact that testing methods influence the results. To solve these problems, near "*worst-case scenario*" laboratory testing standards and standardised field tests[102,103] on key beneficial species are required by law in the EU for pesticide registration. But in Australia, there is little research on pesticide safety to key native species to such rigor. We thus take a cautious approach and suggest that some recently registered insecticides (and new label rates of wettable sulphur against powdery mildew) require further testing before their place in IPM in Australia can be fully established. They are less toxic to natural enemies than the highly toxic pyrethroid, organophosphate, and carbamate insecticides, but domestic and overseas results to date indicate varied toxicity to a range of species, and it remains to be proven that they do not disrupt bio-control by native Australian mealybug parasitoids, LBAM parasitoids, or common predators such as green and brown lacewings (*Mallada signatus*, *Micromus tasmaniae*), predatory bugs (*Nabis kinbergii, Oechalia schellenbergii*), or ladybird beetles. We hope that manufacturers of these products publish refereed scientific data on safety to Australian beneficial species, on the basis of which this IPM guide may be confidently amended.

Cost -benefit analysis

Per hectare cost of pesticide product and application is often the ▶

Table 5. Options for WEEVIL management in established vineyards (IPM-compatible; text in blue IPM-transition; text in red IPM incompatible)

	Monitoring	Chemical control	Bio-control Naturally present	Cultural control Ecological engineering	Bio-control for release
Weevils causing damage in Australian vineyards: **(1) garden weevil** *Phlyctinus callosus* **(2) black vine weevil** *Otiorhynchus sulcatus* **(3) white-fringed weevil** *Naupactus leucoloma* **(4) Fuller's rose weevil** *Asynonychus cervinus* **(5)** *Ecrizothis boviei* native sp., no common name	**Species (1-7):** Bud damage, typical "shot-hole" leaf feeding damage, and canopy defoliation in young and established vines can be very dramatic, but it is often localised to patches within a block. Berries can be damaged later in the season. Monitoring (Table 1) also scouts for adults and damage in the canopy. Wax-dipped corrugated cardboard bands (20 per block, placed around vine trunks, and checked weekly) are recommended (Agriculture WA). **Locate damage patches from early September, tag and inspect over the season to target spot sprays and cultural controls.** Obtain sp. ID to use specific cultural and bio- controls. **Species (1-5):** **Monitor also by exploratory soil digging in vine patches tagged the previous season. Dig at regular time intervals from early Spring to monitor juvenile development into pupae, and to target mid-row cultivation to *c.* 70% pupae** [71]. This controls the part of the pest population found in the soil in vine mid-rows.	**Species (1-7):** **Target adults by spot-spraying damage patches in early Spring when adults emerge; not broad-scale spray use, to minimise damage to bio-control.** Indoxacarb (e.g. Avatar®) is registered for use against garden weevil in Spring, alpha-cypermethrin (e.g. Crop Care Dominex Duo) against garden weevil in non-bearing vines. Both are toxic to beneficials, but indoxacarb is less toxic. Mealybug outbreaks (Table 2) can be induced by broad-spectrum sprays killing natural bio-control. This risk is far too great, and far outweighs any minor labor savings gained by not locating weevil patches. **Broad-scale canopy applications, or butt drenching of vine blocks with insecticides in early Spring, and on annual basis.**	GWRDC Project RT04/17-4 is underway. Ground-dwelling predators can attack adults on emergence from soil, and on their walk to the vine canopy. They can be aided by habitat provision.	**Species (1-5):** **To target juveniles, time mid-row cultivation to desiccate pupae** [71]. This method can be very effective in reducing the pest population, which is difficult to achieve by spraying alone, because immature stages are protected in the soil. Soft vulnerable weevil pupae in the soil are exposed to drying. Optimal timing to *c.* 70% pupae. Actual time differs per each species, and can also differ site to site, and year to year. **Species (1-7):** **To target adults, habitat provision (under-vine mulching, beetle banks, alternate row mowing)** aid ground-dwelling predators, such as staphylinid and carabid beetles, spiders, brown lacewing larvae, earwigs, etc.) to attack adult pests on emergence from soil. **Physical exclusion barriers (sp. 1-5):** Barrier glue or grease bands placed around vine trunks can reduce the number of adults entering the vine canopy, and canopy damage. This need be combined with practices that reduce weevil populations. Large-scale use of barriers is labor-intensive, and may not be economical. **Host plant species (sp. 1-7):** weevils feed on roots and foliage of many plants. Comprehensive identification of host plants and effects of eliminating these from mid-rows remain to be fully investigated. **Species (6):** Removal, composting, or fine mulching of pruned canes.	**To target juveniles of species (2):** Nematode soil drench is available against sp. (2), suggested use is after cultivation see [14] and consult the supplier, EcoGrow
Wood-boring species **(6) vine weevil** *Orthorhinus klugi* **(7) elephant weevil** *Orthorhinus cylindrirostis*					
Further information may be obtained from the garden-weevil-watch web site of DAFWA (www.agric.wa.gov.au), but not all information provided is IPM-compatible. GWRDC Project RT 04/17-4 in the Yarra Valley and a garden weevil management project in Western Australia are underway. Kaolin clay foliar sprays are proving effective in research field trials, they are registered for use in a number of horticultural crops in Australia but not in grapevines [72].					

Table 6. Options for management of GRAPEVINE PHYLLOXERA in established vineyards (IPM-compatible; text in blue IPM-transition; text in red IPM-incompatible)

	Monitoring	Chemical control	Bio-control Naturally present	Cultural control Ecological engineering	Bio-control available for release
Grapevine phylloxera *Daktulosphaira vitifoliae*	**A new molecular diagnostic technique for detecting phylloxera DNA by a genetic PCR probe** that will allow highly sensitive low level detection, quantification of pest infestations, and efficient screening of many samples, has been partly developed [76] (CRCV Project 2.2.3a), and requires further development. **Aerial survey detection by GPS and remote sensing of low vigor areas. These are targeted by ground surveys inspecting root systems and emergence traps Nov-March** [77, 78] (www.phylloxera.com.au) **Chemical and spectral** studies also show potential for phylloxera detection, based on changes in vine physiology following infestation [79, 80]	**No IPM-compatible insecticides are registered in grapes in Australia.** **No IPM-incompatible pesticides are registered in grapes in Australia** including the systemic nicotinoid imidacloprid (e.g. Confidor®). This pesticide has been tested in laboratory and glasshouse trials in Australia [73], but not under field conditions. It has an extremely long half-live in the soil (365 days) and very high water solubility [73, 81] that render it very environmentally hazardous. It is toxic to a common, important predator found in Australia and New Zealand, the brown lacewing *Micromus tasmaniae* [16, 82], and its long persistence predicts that such ability to disrupt naturally present bio-control is likely to be long-lasting. There is an indication of pesticide resistance in some pests [83, 84].	Many generalist ground-dwelling predators may feed on phylloxera juveniles. But to date no studies have been conducted in Australia to quantify this predation.	**Quarantine and hygiene regulations and resistant rootstocks are the primary form of phylloxera management (www.phylloxera.com.au), and are the most commonly used long-term management options.** **An ideal IPM strategy for phylloxera would also include habitat provision for ground-dwelling generalist predators, such as alternate row mowing, and beetle banks (permanent strips of unmoved grass, a reservoir of ground-dwelling predators from which they disperse into crops).** This aids predator populations and increases control of soil and litter-dwelling pests in other crops [85, 86]. Similarly, ground-dwelling predators can attack phylloxera during the vulnerable stage, when phylloxera juveniles emerge from soil, and may reduce the spread of phylloxera within and between vineyards. To date there has been no research on this important aspect of phylloxera control in Australia. Yet this predation concept is well-demonstrated for other soil-dwelling pests and is topical, given some recent rootstock failures in Europe, and the detection in late 2006, of phylloxera in the Yarra Valley, Victoria. **Some composted marc mulches** reduced phylloxera populations emerging from the soil [21], but choice of compost may be important, as green waste was associated with increased phylloxera numbers during the summer months [22]. Further work is needed before recommendations on phylloxera management and mulching can be made.	No bio-control agents are available for release commercially, but research success was reported with entomopatho-genic fungi *Metarhizium anisopliae, Beauvaria bassiana, Paecilomyces farinosus*, and with entomopatho-genic nematodes. [73-75]

key consideration when choosing pesticides. This can lead to the use of cheap broad-spectrum sprays highly toxic to beneficials, damage to naturally present bio-control, and escalating pesticide use as bio-control services diminish. Use of cheap pesticides can often have expensive consequences, if it induces secondary pests or leads to on-going pest problems that would otherwise be avoided by using a more selective product. When short and long-term economic benefits of pest prevention (for example [3]), and environmental benefits, are considered, IPM and bio-control are consistently the better economic option. Use of IPM over many years results in significant benefits in reduced environmental degradation and human exposure to pesticides, in preventing mealybug, rust mite, and two-spotted mite

Table 7. Options for management of other pests (IPM-compatible; text in blue IPM-transition; text in red IPM-incompatible)

	Monitoring	Chemical control	Bio-control naturally present	Cultural control	Bio-control available for release
African black beetle *Heteronychus arator*	Turf and pasture pest introduced to Australia from South Africa in the early 1900s. It is only a pest in vineyards during first few years of vineyard establishment, owing to conversion from pasture. Tolerating such temporary damage is preferable, but may not always be realistic, due to instances of considerable damage in some regions in the first year of vineyard establishment (replanting, additional trellis training, and a delay in production). Thus at times a pre-planting treatment has been used. Pest numbers prior to planting and spraying can be evaluated with pitfall traps.	**Pre-planting broad-spectrum insecticide spray** is sometimes applied in an attempt to prevent damage during vineyard establishment. **Broad-spectrum insecticide use after planting** is often followed by severe rust mite outbreaks in the young plantings and associated drift-areas (M. Bernard, pers. comm.), due to suppression of predatory mites, which control rust mite (Table 4). Where planting stock may have contained bud mite, risk of severe bud mite damage in the young vineyard is also increased. Damage to bio-control agents of other pests also occurs, and can lead to further pest outbreaks, outweighing initial control benefits gained by spraying for African black beetle.	Some generalist ground-dwelling predators may feed on this pest.	Cereal or canola crop rotations for up to two years prior to vine planting may be used to overcome these pest problems without the use of insecticides.	Nematode soil drench (EcoGrow, Australia) targeting young larvae, generally present *c.* November, is effective [14]. For precise application contact the supplier.
European earwig *Forficula auricularia*	**Monitoring and IPM strategy:** Scanning vines in first few weeks after bud burst, during routine monitoring for pests and beneficials (Table 1). Traps of corrugated cardboard, or black plastic sleeves containing diet bait, can be placed around vine posts to monitor numbers, and are used in studies on this species [87]. Accepting minor damage is part of an IPM strategy, especially since this species has now been identified as a key predator of LBAM larvae in vineyards at night. European earwigs can aestivate in hot Australian Summer conditions. **Damage symptoms:** Localised damage (nibbled vine shoots) in early Spring has been attributed to European earwigs. But damage is difficult to separate from early Spring LBAM damage to buds and leaf rosettes, and so may be easily overestimated. The species causes no damage to vines later in the season. Feeding damage is also reported in apple varieties in Australia, where it was recently evaluated, indicating negligible damage (<2.5%) in only some apple varieties and some times, and only in the absence of prey [88]. Direct damage to stone fruit can be considerable, but is successfully prevented in organic production by Teflon-banding tree trunks. **Evidence of predator status:** New research using video analysis of field predation shows this species to be a key, significant predator of LBAM larvae in the canopy, and on the vineyard floor at night [89]. It was also noted to feed on LBAM in extensive LBAM studies [39], and on pest mites in Australia [90]. It is recognised as an important generalist predator in European vineyards and orchards (of grape moth - *Eupoecilia ambiguella*, aphids, and psyllids) [91-96]. A superficially similar native predatory earwig (*Labidura truncata*) also occurs in Australia [97], and is present in vineyards.				

outbreaks, vine collapse due to vine-leaf roll virus (transmitted by longtail mealybug), and primary bud necrosis (PBN) due to bud mite. Some risks associated with potentially exceeding MRLs may also be reduced. Moreover, the full economic benefits of sustainable wine grape production are yet to be realised by well-designed marketing of sustainably produced wines, and by aiding regional differentiation of wines in the international market in this way. All these benefits need be evaluated by a comprehensive economic review beyond the scope of this project.

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Some other useful resources

BioBest pesticide side-effects manual (overseas beneficial species only: http://www.biobest.org/); Environmental Management in Australia (see AWIS Systems Map in www.WFA.org.au); Organic viticulture: an Australian manual (www.dpi.vic.gov.au).

Disclaimer

IPM-incompatible practices (text in red) are listed here only for comparative purposes and are not recommended by this guide. Information on the use of pesticides herein are the professional view of the authors, and are based on current (2006) knowledge which will be updated as new information from tests on beneficial species is published. The advice provided in this publication is intended as a source of information only, and readers are advised to seek guidance in the field from experienced IPM-specialists. Always read the label and consult

Table 8. Options for IPM-compatible management of GRAPEVINE DISEASES to conserve beneficial invertebrates.
Biological organisms with known activity against pathogens not yet developed as viable commercial control options are also listed.
The fungicide list is based on limited Australian and New Zealand data available to date and a literature review on overseas beneficial species. Many fungicides here have not been widely tested on native Australian species, and toxicity varies between species. This list may thus change as new data become available. Some fungicides here may have adverse effects on beneficials when used frequently, or as low volume sprays of concentrated tank mixes, or per higher than currently registered label rates.

Disease	Fungicides with low toxicity to beneficials Chemical name and example of a product	Biological control organisms with known activity against pathogen Not registered in Australia*	Cultural controls and potential future measures
Powdery Mildew *Erysiphe necator*	■ triadimefon – e.g. **Accord** 125 EC ■ azoxystrobin – e.g. **Amistar** WG ■ hexaconazole – e.g. **Anvil** ■ triadimenol – e.g. **Bayfidan** 250 EC ■ pyraclostrobin – e.g. **Cabrio** ■ trifloxystrobin – e.g. **Flint** 500 WG ■ tebuconazole – e.g. **Folicur** 430 SC ■ quinoxyfen – e.g. **Legend** ■ myclobutanil – e.g. **Mycloss** ■ spiroxamine – e.g. **Prosper** 500 EC ■ fenarimol – e.g. **Rubigan** 120 SC ■ pemcozole – e.g. **Topas** 100 EC ■ wettable sulphur (WS) – e.g. **Thiovit** Jet Limited, lower concentration use of WS is recommended to conserve beneficials; also by IOBC Guidelines for Integrated Grape Production [5].	**Filamentous fungi** *Ampelomyces* sp. (e.g. AQ10®; USA) *Acremonium* sp. *Cephalosporium* sp. *Cladosporium* sp. *Gliocladium* sp. *Fusarium* sp *Penicillium* sp *Tilletiopsis* sp. *Trichothecium* sp **Bacteria** *Bacillus* sp (e.g. Serenade®USA) **Yeast and yeast-like fungi** *Pseudozyma* sp. (e.g.Sporodex®; Ireland)	Disease management is aided by practices that reduce canopy density, relative humidity, and pathogen inoculum levels, and also by site selection, row orientation, and by preventing vine shading (by adjusting distances between trees and first vine rows). Disease 'hot spots' can also be reduced by preventing water pooling in wheel ruts. Use of tall cover crops or alternate grass row mowing (outside frost danger time) have been suggested for trapping spores released from fungal structures over-wintering in the soil. For bunch rot, minimise planting of susceptible varieties in low lying areas prone to frost and poor air drainage, or close to large water bodies where relative humidity is prolonged. Selective bunch tinning to reduce crop load and advance harvest date is an effective way to avoid severe bunch rot in cool climate regions, where berry ripening may extend into periods of autumn rains.
Downy Mildew *Plasmopara viticola* **Phomopsis cane and leaf spot** *Phomopsis viticola*	■ dimethomorph – e.g. **Acrobat** WG ■ phosphorous acid – e.g. **Agri-Fos** 600 ■ azoxystrobin – e.g. **Amistar** WG ■ chlorothalonil – e.g. **Barrak** 720 ■ copper hydroxide – e.g. **Blue Shield** DF ■ copper oxycholride – e.g. **Brycop** ■ pyraclostrobin – e.g. **Cabrio** ■ captan – e.g. **Crop Care Captan** WG ■ dithianon – e.g. **Delan** 700 WG ■ trifloxystrobin – e.g. **Flint** 500 WG ■ cuprous oxide – e.g. **Flocop** ■ metalaxyl/ copper oxychloride or hydroxide – e.g. **Axion Plus, Ridomil Gold Plus**** ■ metiram – e.g. **Polyram** DF (IPM-transition); limited use is suggested due to some toxicity to some Australian predatory mite species [7].	**Filamentous fungi** *Fusarium* sp *Trichoderma* sp. **Bacteria** *Bacillus* sp. *Pseudomonas* sp. **Phomopsis Type II diagnosis** is essential prior to applying fungicides, given that the similar-looking Phomopsis Type I (re-named Diaporthe) is reported to have no negative impact on vines, and is not considered a pathogen. Unnecessary early season sprays (at bud burst, and 10-14 days later) may thus be prevented.	**Canopy density/ humidity** can be manipulated by row orientation, trellis design, pruning, trimming and leaf plucking techniques and through altering vine vigor by limiting irrigation and fertilizer use. Cover crops and alternate row mowing can also reduce vine vigor by competing with vines for resources. **Pathogen inoculum levels** can be reduced by vineyard sanitation. Vine prunings are mulched in situ, or are removed from mid-rows and mulched, composted, buried, or burned. Composting/fermenting are the preferred options as composts can be applied to vines, to improve soil quality, water holding capacity, vine health and resistance to disease, and cycle carbon fixed in organic molecules, instead of emitting CO_2 by burning. New research also shows that mulches lead to significant reduction in Botrytis cinerea primary inoculum and bunch infections by breaking pathogen life cycle via soil microbial activity during over-wintering on the vineyard floor [18-20]. **Temperature-based models of shoot growth** estimate the amount of new shoot tissue developed since last fungicide application, and underlie advice provided by the weather service on timing protective fungicide sprays in some EU countries. Similar models are being developed in Tasmania [98]. **Aerated compost teas** (watery extracts of compost containing many microorganisms and nutrients) [99] show some disease suppression ability when applied to foliage and fruit [100, 101], but more research is required prior to their commercial use.
Botrytis bunch rot *Botrytis cinerea*	■ azoxystrobin – e.g. **Amistar** WG ■ chlorothalonil – e.g. **Barrak** 720 ■ captan – e.g. **Crop Care Captan** WG ■ boscalid – e.g. **Filan** ■ H_2O_2, peroxyacetic acid – e.g. **Peratec** ■ pyrimethanil – e.g. **Scala®** 400 EC ■ cyprodinil, fludioxonil – e.g. **Switch** ■ procymidone – e.g. **Sumisclex** 500 **Warning! S7 Poison** ■ fenhexamid – e.g. **Teldor** 500 SC	**Filamentous fungi** *Trichoderma* sp. (e.g. Vinevax®, Australia; Sentinel®, New Zealand; Trichodex®, Israel) *Ulocadium* sp. (e.g.Botryzen®, New Zealand) **Bacteria** *Bacillus* sp. (e.g. Serenade®, New Zealand) *Pseudomonas* sp. **Yeasts** - (e.g. Shemer®, Isreal)	

* Organisms listed are not available as registered products in grapes in Australia (except for *Trichoderma* sp.) and their importation without a permit is illegal. Products registered in New Zealand, and elsewhere are listed. ** Do not confuse with similar brand name products containing metalaxyl and mancozeb (toxic to predatory mites).

withholding periods and MTL requirements before using any of the products mentioned. The use of S7 poisons is not recommended by this guide.

The State of Victoria and its employees, and the GWRDC do not guarantee that this publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

Agricultural Chemical Users Permit (ACUP): Victorian regulations require the users of some pesticides to hold an ACUP, or be under the direct supervision of an ACUP holder, and to make and keep accurate records of use for at least two years. Pesticides requiring ACUP are S7 poisons, and certain other herbicides. S7 poisons are indicated in this guide by: 'Warning S7 poison'.

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AgNote: Enhancing beneficial insects and mites in vineyards: providing nectar, pollen, and shelter in vine rows

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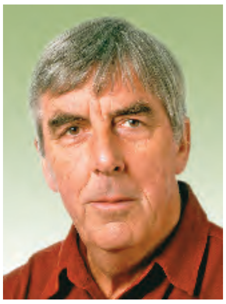

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Alternate row mowing of mid-row grass

Alternate row mowing provides habitat, shelter from low humidity and summer heat, and pollen as a food source for natural enemies. Vineyard generalist predators, such as brown lacewings (*Micromus tasmaniae*), damsel bugs (*Nabis kinbergii*), ground-dwelling predatory beetles and spiders, commonly found in mid-row grass can be aided by habitat provision. Many predatory mite species supplement their diet with pollen and some species can even be reared on pollen alone in the laboratory. Providing grass pollen can help predatory mite populations to thrive even when numbers of prey are low, thereby increasing potential predation[1]. The use of alternate row mowing may be limited in some regions due to spring frosts, and summer drought. Where grass needs be cut for these reasons, a minimum of 10cm is best to preserve some habitat, grass roots and the ability of the grass to compete with broad-leaf weeds. Side-throw slashers place cuttings under vines, creating a mulch layer that further improves beneficial habitat and soil structure, reduces water evaporation, water run-off, and botrytis incidence on grapes.

Providing nectar

What makes a good nectar source?

Nectar is a vital food source for many insects, including adult parasitoid wasps, the larvae of which feed on LBAM larvae and other pests. However, latest research shows that only nectar with particular 'sugar signatures' (sugar content and proportions) is beneficial for these wasps. Nectar chemical analyses are followed by evaluations of nectar on beneficial species (and pests) in the laboratory and in the field. In addition, flower shape must allow access to nectar deep inside flowers, the plant (if annual) must be fast-growing and flower within a few weeks of sowing, and perennials should flower at times synchronous with the activity of natural enemies. Plants must be compatible with vineyards in low water and nutrition needs, low weed potential, the nectar and other plant features must not enhance pest damage. This takes years to establish! Research in this area is vital, and growers should only deploy nectar sources determined by research. Ten years of research in New Zealand (Lincoln University) and collaboration with Charles Sturt University in Australia established three non-native nectar sources suitable for vineyards so far. But new screening of native plant nectars is indicating many more suitable candidates in New Zealand, and such research on Australian native plants has a great potential to benefit Australian growers in the future.

Suitable nectar plants and benefits

Buckwheat (*Fagopyrum esculentum* Fig.1a) is so far the best source of nectar for vineyards. Phacelia (*Phacelia tanacetifolia-*

Fig. 1. Nectar plants in one in every 10 rows: (a) buckwheat; (b) phacelia; (c) white alyssum under-vine strips (©Jean-Luc Dufour, Waipara Hills Vineyards, New Zealand).

Fig.1b) is also suitable but its utility is not as high as that of buckwheat, and it self-seeds to a degree. Both were tested on the most abundant LBAM parasitoid in Australian and New Zealand vineyards, the Australian native wasp *Dolichogenidea tasmanica*[2-5] parasitising LBAM larvae. Access to this nectar significantly increased *D. tasmanica* lifespan, egg load, and LBAM parasitism compared with water only in extensive New Zealand studies[6-11], and reduced LBAM and other leafrollers below economic thresholds without a need to spray in vineyards where buckwheat was sown in every 10th mid-row. Buckwheat is now used by grape growers in Hawkes Bay, Waipara, Marlborough and Central Otago, showing that leafroller damage is reduced to below the economic spray threshold and saving up to NZ$250/ha/year.

White alyssum (*Lobularia maritima* Fig.1c), a drought tolerant self-sowing annual, native to slopes and cliffs of the Mediterranean, is a good nectar source for the minute parasitoid of LBAM eggs *Trichogramma carverae*[12]. It is low-growing and well suited to under-vine planting. Beneficial species, such as parasitoids of mealybugs and scales, and predators whose adult stages feed on nectar (e.g. hoverflies and common green lacewings *Mallada signatus*) may also be enhanced by providing nectar, and this could help prevent mealybug outbreaks. But nectar has not yet been evaluated for these Australian species.

Use these practices once IPM-Step I is adopted: sprays toxic to beneficials are minimized and pests are monitored every 7-10 days over the growing season[13].

Australian experience using buckwheat

Buckwheat has been successfully trialed in 2006-07 in a 10ha Chardonnay block, Adelaide Hills, SA; contact the authors for more information.

How to use buckwheat

Spacing. Nectar source in 1 of every 10 rows (25m) results in no decline in LBAM parasitism across rows. This was carefully worked out by rubidium marking nectar-feeding *D. tasmanica* wasps, and studying their movement, abundance, and parasitism rates away from the nectar source[14]. Spacing ideal for *T. carverae* is likely to be similar.

Sowing and agronomy. Direct-drill (2cm deep) early November and up to twice more in off-set rows at three week intervals, at a rate of 45kg/ha (0.5kg/100m row). The cost of seed in New Zealand is about 67c/kg, this means 34c per 100m of row! Water-in after drilling (again if very dry), but the plant is otherwise drought tolerant. All cultivars are suitable. Buckwheat has exceptional agronomic qualities due to adaptation to its native habitat in the dry steppes of Asia that make it an excellent cover-crop. It takes only 5 weeks to flower (November planting), or 3 weeks (Jan/Feb planting). It adapts to drought by growing to low height (*c*.15cm) yet flowering sufficiently to supply nectar, and grows knee-high, flowering profusely, if more water is available. The only disadvantage is that it is annual and needs re-sowing each year. This is necessary until research on Australian native plants finds suitable perennial nectar plants.

Seed suppliers

Australia: Buckwheat is grown in Australia for the soba noodle market, and local seed is available. Order by April to guarantee stock. Highleaze Seeds, Smeaton, Victoria 3364; Lang Seeds Woodside, Adelaide Hills, SA 5244; Mirfak Pty Ltd, PO Box 38, Benalla, Vic 3672; Organic Buckwheat supplier: Kialla Pure Foods M/S, 664B Greenmount, QLD 4359; approximate cost: A$1.25/kg.

New Zealand: Midland Seeds, 393-405 West St, PO Box 65, Ashburton, NZ; Ph +64 33081265, Fax +64 33081266; email: office@midlands.co.nz, web www.midlands.co.nz. Buying seed directly from New Zealand may not be permitted in Australia.

Please contact the authors if you wish to try using nectar plants in your vineyard, or for further information. Martina Bernard can be contacted on +61 0409 936503, martinab@unimelb.edu.au Stephen Wratten can be contacted on +64 3325 3838 ext 8221, wrattens@lincoln.ac.nz

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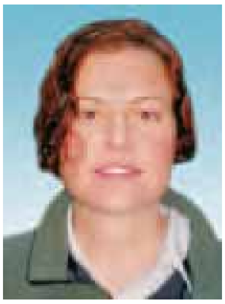
Beneficial insects and spiders in vineyards: Predators in South-East Australia

The first study of generalist insect predators and their seasonal changes in Australian vineyards



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Introduction

Modern viticulture and environmentally aware world markets increasingly require that vineyard management be as environmentally sound as possible. Most agree that this is a worthwhile undertaking. There has been a tremendous ground-swell of interest in this topic, demonstrated by a demand for seminars, by the adoption of rust mite IPM in Australia, reducing pesticide use toxic to predatory mites [1-3], and by the greening of a whole wine region in New Zealand (www.lincoln.ac.nz/story13772.html; www.waiparawine.co.nz/index.cfm/research/greening_waipara.html). It is clear that, given a chance in the form of practical, economically feasible and agronomically well-considered guidelines, many growers and wine companies choose to adopt IPM and bio-control. It is also clear that in Australia they face a problem in a lack of comprehensive, site-adapted advice on how to do this. Some growers go ahead regardless obtaining information from many sources, including overseas (such as Yalumba, Brown Bros, or Agribusiness Research & Management P/L), or engage expert IPM services (IPM Technologies, Biological Services, Bugs for Bugs). Other growers adopt alternate row mowing to provide shelter, pollen and nectar for beneficials (such as Riverland growers, based on Phylloxera and Grape Idustry Board of South Australia 2004-5 seminars). Others watch such developments with interest, waiting to see how the industry-leaders fare. This overview is for all these growers. It is a photo gallery of beneficials, with their seasonality in vineyards summarised based on research across four vineyards in/near the Yarra Valley in 2003-05. We hope it will bring to life the terrific range of vineyard beneficials, and aid the understanding of vineyards as living agro-ecosystems, whose tremendous natural biological control potential can be harnessed for environmental, cost saving, and marketing benefits.

Sustainability and bio-control

Naturally occurring biological control of pests is an awesome force nature provides free of charge to human agriculture. It greatly contributes to the control of potential pests, even in highly modified agricultural landscapes, particularly where IPM or organic farming practices are used [4, 5]. It is called an Ecosystem Service (ES): a key ecosystem function that arises from the sum total of all interactions of all organisms (biodiversity) within the system, water, soil, and climatic factors. Together these make the complex web of interdependent functions which eventually delivers its individual components such as ladybird beetles, predatory mites, spiders, and lacewings to your vines. Other examples of ES crucial to human life are pollination, water filtration by forests, fisheries, composting, soil mineralisation, and CO_2 removal from the atmosphere by photosynthesis [6].

What are nature's services (ES) worth to the economy?

It is interesting to consider what can happen when an ES is disabled. For example, what would happen to the world food supply, if pollination by bees was impaired? What might be the flow-on effects to other human enterprises? This is not as far-fetched as it may seem. For example, since 1990 outbreaks of a pest mite and disease vector (*Varroa destructor*; not in Australia) of honeybees resulted in a major decline in bee colonies across the USA, reduced agricultural pollination, and large crop losses [7]. The point is: we do not usually put monetary value on nature's services. We take them for granted, and our accounting systems ignore their contribution (except as harvested products) to national and world economies. Such views come to us by force of habit from the 19th and earlier centuries. We simply assume that nature will go on as it always has, inexhaustible and plentiful, the way it seemed when our means to disrupt it were far more modest. Is this view still valid today, or is it perhaps outdated? Recently, the global value of biodiversity was estimated at US $3 trillion per year, and of all ES combined [6] at a minimum of US $16-54 trillion per year, of which $100 billion per year was attributed to pest and disease suppression by natural enemies in crops world-wide [8, 9]. Despite an inherent degree of ▸

uncertainly, these valuations clearly indicate the importance of conserving ES. Preventing damage to natural biological control and restoring ES of agricultural systems are therefore key aims of sustainable food and fiber production, increasingly recognized as critical to maintaining high-productivity agriculture into the long-term future [10-12]. A vineyard level cost-benefit review of IPM & bio-control will appear in the November issue.

Beneficials in your vineyard

Generalist (multi-feeding) insect predators, spiders, and parasitoids of LBAM and mealybugs are important providers of biological control ES in vineyards and orchards. This is their story. Here is what happened over two growing seasons in well-established IPM vineyards, situated near large blocks of remnant native vegetation (a landscape feature found to enhance beneficials overseas), using a basic on-site beneficial enhancement (alternate row mowing) in 2004-05. Sprays toxic to beneficials were eliminated for 3-5 yrs prior to this study. Wettable sulphur use in the study blocks did not exceed 300g/100L and 3kg/ha. Mimic®, BT, and one Success® spray per season in one site (2004) were the only insecticides used, except for an accidental Avatar® spray (2002) in one site prior to this research. Monitoring of pests and beneficials was used to decide when to spray & when not to spray. Longtail mealybug (*Pseudococcus longispinus*) was found in one site (03-4), and in another (04-5). It was contained to a few vines and controlled without pesticides by the next spring. We found a succession in peak abundance of beneficial species over the season. This species complex (predators) is described here (for LBAM parasitoids - see October 2006 issue). We show that biological control of LBAM, vine moth and mealybugs is not delivered by a single key beneficial (an idea based on how pesticides work), but by a whole range of organisms that coincide, or succeed one another over the season, each contributing to the overall pest control to a greater or lesser degree (Fig.1).

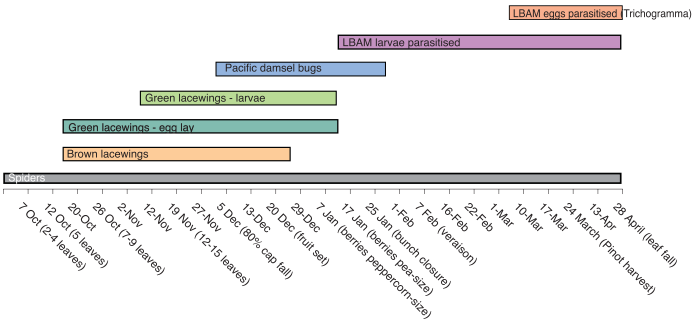

Fig. 1. Approximate periods of high abundance of beneficials (predatory mites not included) in the study sites; growing seasons 2003-05

Sampling methods & limitations

Two well-established methods were used alongside one another; day-time only.

- Direct observation of the vine canopy: 100 random vine shoots replicated 4-6x (n=4-6), were examined from shoot tips, both sides of leaves, to 10 cm cordon section below each shoot; 400-600 shoots were checked weekly from early spring to leaf fall (7 Oct - 28 April). Only freshly laid lacewing eggs were counted (no emerged eggs), therefore numbers are an underestimate of eggs laid each week.
- Vacuum suction sampling of long inter-row grass: 8-11 randomly chosen long grass sections (1m^2 ea) were vacuumed for 60 sec every 14 days (20 Oct-28 April); each catch was captured in a nylon bag attached to the suction tube, killed immediately by ethyl acetate vapor, and sorted in the laboratory. Graphs here show trends found in all four IPM-sites over two growing seasons 2003-05.

However, seasonal population changes of beneficials need be studied over a longer period, and in other regions; a task beyond the funding scope of this project. In dynamic, living ecosystems, numbers, peak times, and individual species can vary between sites, regions, and years. Full scientific data are being prepared for publication elsewhere. Predatory mites were not studied.

Brown lacewings (BLW)

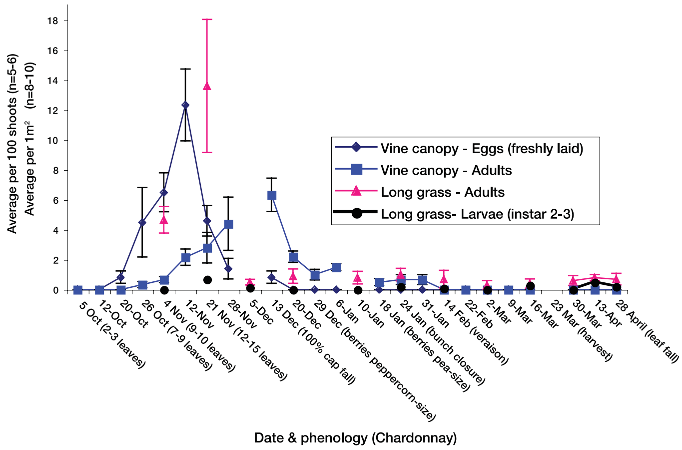

Fig. 2. BLW in the vine canopy & vine inter-rows in 2004-05: average per 100 vine shoots (± S.E.), and per 1m^2 of long grass vacumed for 60 s (± S.E.)

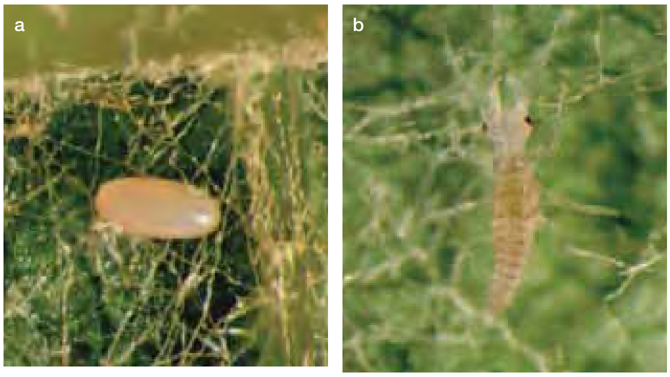

Fig. 3. (a) BLW (*M. tasmaniae*) egg, (b) freshly hatched larva; 32 x mag (© Semeraro & Bernard)

Micromus tasmaniae (Neuroptera: Hemerobiidae) (Fig. 2-4) were found in very high numbers in the vine canopy, and in long grass inter-rows. Besides spiders, it was the most abundant beneficial species active early in spring, reflecting adaptation to cold [13]. Adults co-occurred in high numbers in the canopy and long grass inter-rows from early spring until c. end of December. Thereafter numbers were low in both strata. Adult numbers peaked some weeks earlier in inter-rows than in the canopy (mid Nov-mid Dec), when averages of 6.3 ± 1.12 per 100 shoots and 13.6 ± 4.44 per 1m^2 of long grass (Site I- Fig.2), and 6.5 ± 0.85 per 100 shoots & 10.2 ± 1.56 per 1m^2 of long grass (Site II) were recorded. Interactions between populations in inter-rows and the canopy indicate the importance of long grass habitat to canopy visits and egg-lay by adults. Eggs were laid in the canopy for c. 6 weeks from 20 October-3 December (Pinot Noir: 6 leaves separated - flowering). Peak egg-lay occurred 3-12 November (PIN: 10 leaves), averaging 12.3 ± 2.39 eggs per 100 shoots (Site I), and 27.3 ± 2.69 (Site II). Larvae were also found in the canopy, and eggs in inter-rows, but sampling methods were not accurate for these life-stages.

Green lacewings (GLW)

Mallada signatus (Neuroptera: Chrysopidae) (Fig.5-6) was the most abundant GLW species. Eggs were found in the vine canopy from early October to late January (PIN 2-4 leaves-bunch ▶

Fig. 4. (a) BLW (*M. tasmaniae*) larva (final instar), (b) adult, (c) pupa (© Semeraro)

closure), peaked late October-mid December (PIN: 7-9 leaves-flowering), and reappeared late March. Larvae were found in canopy November-January, with the highest average abundance at flowering; 12.5 ± 1.34 per 100 shoots (Site I), and 11.2 ± 1.11 (Site II- Fig.5). Few adults were found in the canopy, and no life-stages were found in long grass at any site for the entire season, indicating that:

- GLW (*M. signatus*) did not reproduce or reside in inter-row grass
- egg-lay visits by adults to the vine canopy occurred at night
- adults migrated to lay eggs in vines from surrounding remnant vegetation or from shrubs and trees (not ground cover) within the site.

This is supported by evidence of long nocturnal migratory flights of overseas GLW species. GLW (*M. signatus*) is therefore less likely to be exposed to pesticides than BLW (resident in vine inter-rows), and may lay eggs in vines soon after broad-spectrum pesticide use if abundant in the surrounding landscape. This may in turn lead to the wrong assumption that pesticides were safe to eggs and larvae present in vines at spray application.

Brown and green lacewings are most studied as aphid predators in cereals and corn, but predation on other pests in many other crops overseas is also well-established [14, 15]. Yet to date there is no quantitative evaluation of BLW or GLW feeding in Australian vineyards. BLW (*M. tasmaniae*) commonly occurs throughout Australia [13, 16, 17], including in vegetables and cotton [18-20]. Feeding on longtail mealybug [21, 22] and LBAM larvae [23] was recorded. GLW (*M. signatus*) is also common throughout Australia [24-26], and is an important predator in grapes feeding on LBAM, mealybugs, and vine scale (Horne & Altmann unpublished data), and in citrus and other crops [27-29]. Feeding on longtail mealybug [21, 30], and on LBAM eggs and larvae [23] was recorded. GLW species overseas feed on mealybugs [31-34]. *M. signatus* is available commercially in Australia. GLW do not occur in New Zealand.

Pacific Damsel Bugs (PDB)

Nabis kinbergii (Hemiptera: Nabidae) (Fig. 7) was resident and

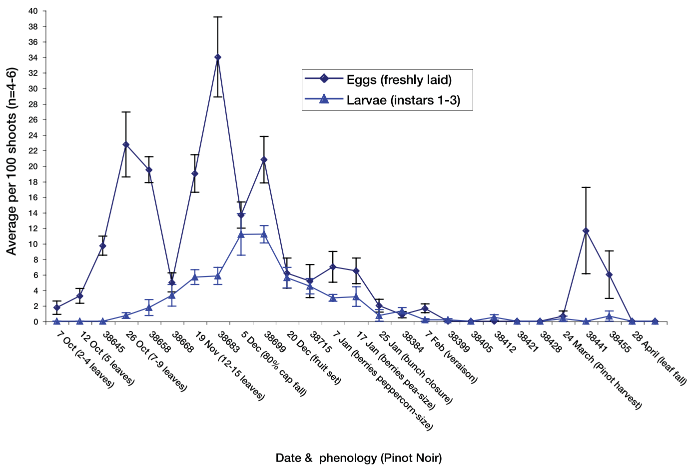

Fig. 5. GLW eggs & larvae in the vine canopy: average density (± S.E.) - Yarra Valley 2004-05

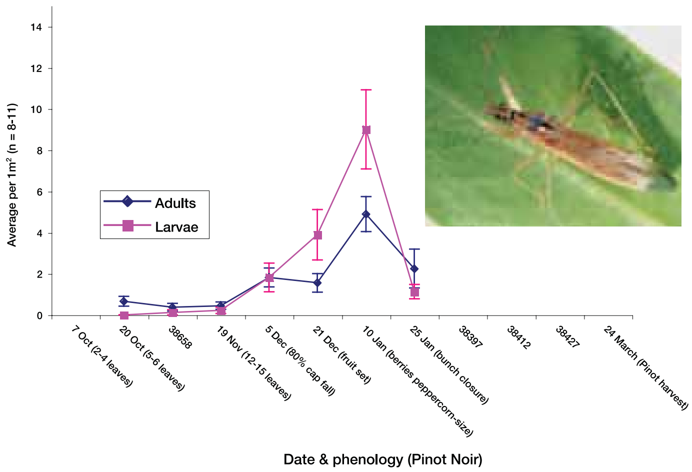

Fig. 7. PDB adults and larvae in long grass inter-rows: average density per 1m2 of long grass vacumed for 60 s (± S.E.) - Yarra Valley 2004-05

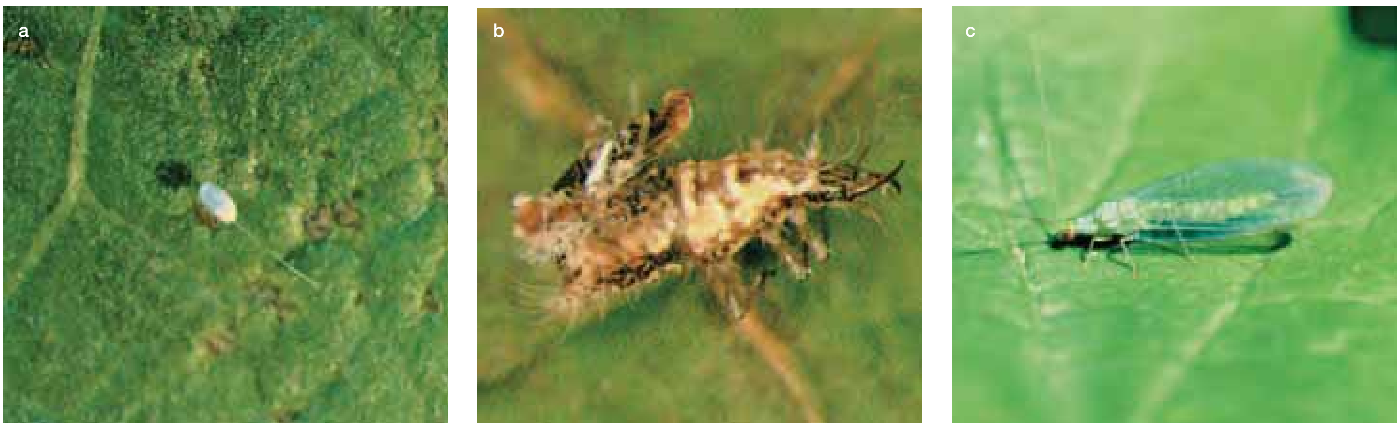

Fig. 6. GLW (*M. signatus*) (a) egg (note typical stalk), (b) larva (note trash carried as camouflage) (© Semeraro & Bernard); (c) adult (© Bernard)

reproducing in long grass inter-rows from 20 Oct (Site I) and 20 Nov (Site II) (PIN 5-6 leaves, 12-15 leaves) until *c*. end of March. Peak abundance was recorded in both sites 10 Jan (PIN berries peppercorn-size): 13.9 adults and nymphs per 1m^2 of grass (Site II-Fig.7), and 3.6 (Site I). Very few PDB were found in the vine canopy throughout the season during the day. This does not indicate lack of interaction between inter-rows and vine canopy, as night insect activity (far greater than day activity) was not sampled. PDB is widespread in Australia and common in many vegetable crops and cotton, feeding on soft-bodied adult insects, eggs and caterpillars [19, 20]. DB were the most abundant insect predators in Californian vineyards [35].

Spiders (Araneae)

Spiders were the most abundant predators found in the vine canopy. They were active already at budburst (webbing between wires), before any other beneficials were found on the developing shoots. Their numbers increased over the season, peaking in the canopy when spiderlings emerged from egg-sacks (Site I-Fig 8). Different spiders were collected from the canopy, and from long grass inter-rows, suggesting that ground and canopy spider assemblages are quite separate, as in Californian vineyards [36, 37]. Ground spiders may thus have little relevance to vine canopy predation. Two most common species in the canopy were the well-known *Eriophora biapicata* (Family: Araneidae) (Fig. 9), building large webs spanning across vine rows, and *Badumna sp*. (Family: Desidae) (Fig. 9), building small tunnel-like webs between shoot tips, between large overlapping leaves, or inside bunches. Many spiders feed on LBAM larvae [23]. We found LBAM adults in webs on trellis wires very early in spring, suggesting an impact on the first seasonal LBAM flight. Spiders are important in pest suppression in many crops, including cotton and cereals [38-40].

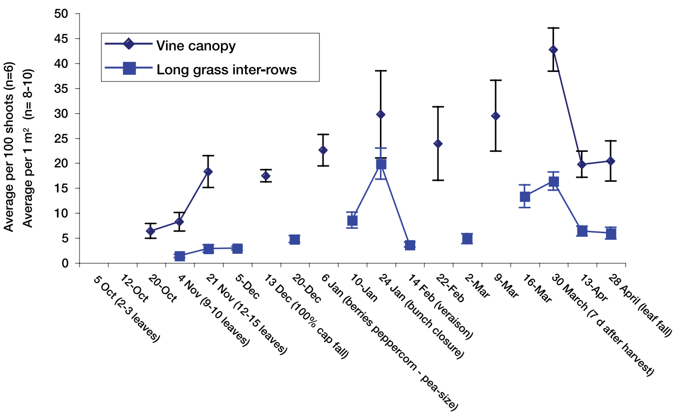

Fig. 8. Spiders (all species): average density per 100 vine shoots (± S.E.), and per 1m2 of long grass vacumed for 60 s (± S.E.)

Fig. 9. Two most common spider species found in the vine canopy (Yarra Valley) (a) *Eriophora biapicata*, (b) *Badumna* sp. (© Bernard)

The numbers of beneficials were very high! To put this into perspective, consider how many 100 shoot lots, and how many square meters of inter-rows there are in a vineyard. The picture that emerges is that of whole 'armies' of small, extraordinary creatures, working for you in pest control night and day; with no overtime, health or environmental risk incurred. In many cases, all you have to do is:

- not kill them by broad-spectrum sprays (harmonise pesticide use with beneficial care)
- manage vine inter-rows to enhance them; consistently over time.

Ladybird Beetles (Coleoptera: Coccinellidae)

Six species were found in the vine canopy. Ladybird beetles were found in much lower numbers (Fig.10) than the predators above, except for *Stethorus*; the black, tiny pinhead-sized, mite-eating ladybird (Fig. 11). Stethorus predation on two-spotted ▸

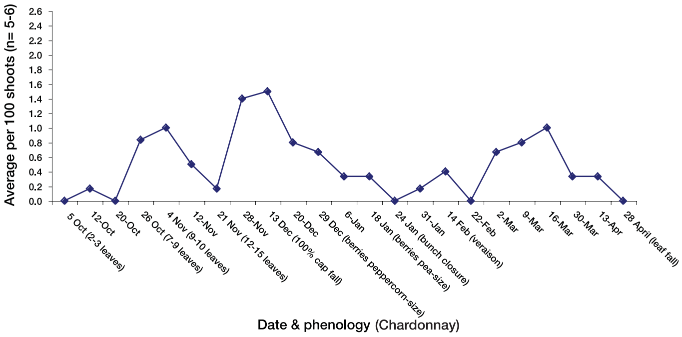

Fig. 10. Ladybird beetles (all species): average density per 100 vine shoots Yarra Valley 2004-05

Fig. 11. *Stethorus* ladybird adult and larva (pin-head size) feeding on TSM (© DPI Knoxfield)

Fig. 12. *Diomus* ladybird adult (sesame seed size); 20x mag. (© Semeraro & Bernard)

mite (TSM, *Tetranychus urticae*) is well-documented in lucerne, raspberry, pome and stone fruit in Australia [41-44]. Its numbers can be very high in late season in vineyards where TSM or other pest mites are present. In such vineyards, *Stethorus* ladybirds are an invaluable ally to growers, achieving TSM control together with predatory mites, but with the advantage of fast movement to TSM patches by flight and extremely high feeding rates. This achieves control late in the current season (before TSM over-winters), and TSM-free vines the next spring. This is invaluable because TSM is resistant to most miticides. The products that work are extremely expensive, and are not registered for wine grapes in Australia. Other species found in all sites were the native: *Diomus notescence, D. sydneyensis* (Fig.12), *Harmonia conformis* (Fig.13), *Coccinella* transversalis (abundant in Riverland vineyards, Altmann & Weppler, unpublished data), and *Hippodamia variegata* (Fig.14) recently introduced to Australia.

Other predators

ROVE BEETLE (Coleoptera: Staphylinidae) adults of one species were found in the vine canopy from early spring until c. mid-December in all four sites studied, and again in early March. Its feeding habits are not known, but other rove beetle species are predators in vegetables, and cereal crops. Other commonly found predators were HOVER FLIES (Diptera: Syrphidae) (Fig. 15) which have predatory larvae feeding on aphids and young caterpillars, and ROBBER FLIES (Ascilidae) (Fig. 16) that catch insects prey in mid-flight. SHIELD BUGS *Oechalia schellenbergii* (Hemiptera:

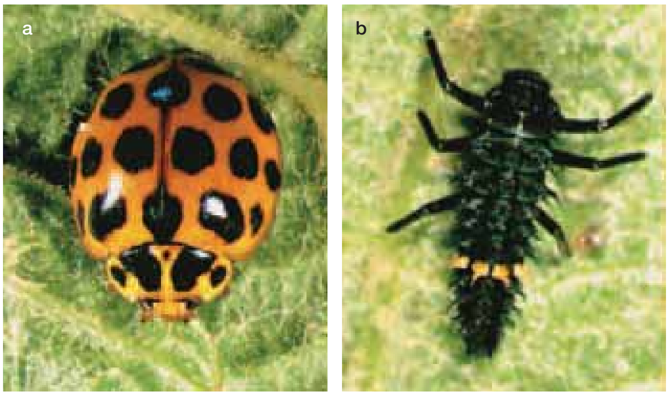

Fig. 13. *Harmonia* (common spotted ladybird) (a) adult, (b) larva (© Semeraro & Bernard)

Fig. 15. Hover fly adult (© B. Lockyer, University of Southampton, UK). Photo taken by Professor Steve Wratten's associate as part of joint research.

Fig. 14. *Hippodamia* ladybird (a) adult, (b) larva (© Semeraro & Bernard)

Fig. 16. Robber fly adult (© Bernard)

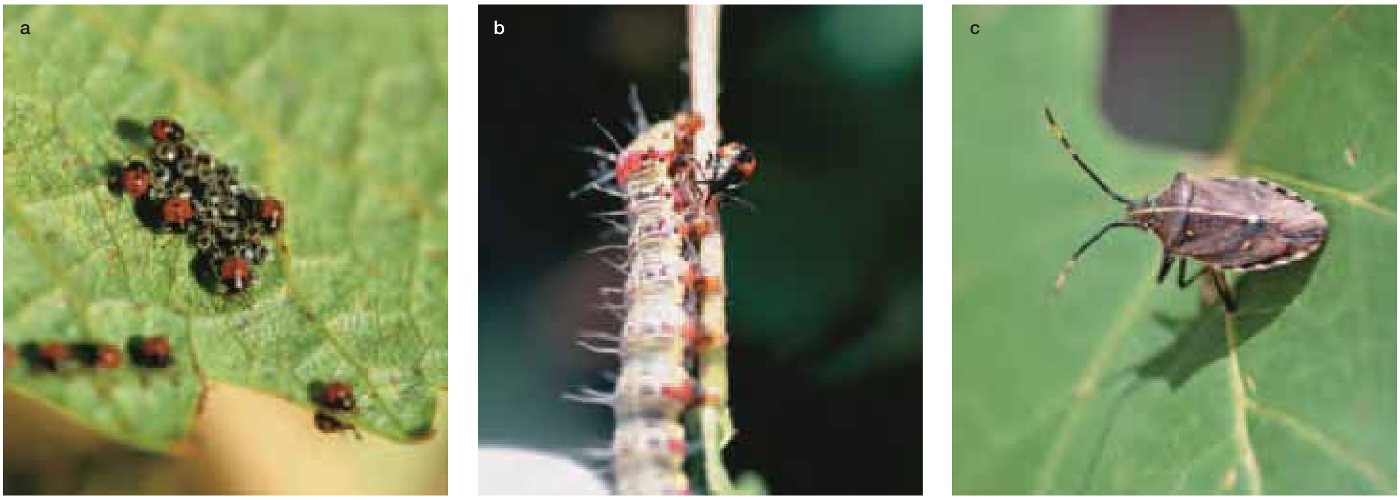

Fig. 17. Predatory shield bug (*O. schellenbergii*): (a) egg-raft (typical metallic-sheen) & newly emerged nymphs, (b) older nymph feeding on vine moth larva, (c) adult (© Bernard)

Fig. 18 Predatory thrips (*H. victoriensis*) (a) egg, (b) larva (© Bernard)

Fig. 19. Predatory mites (Phytoseiidae) ©Bernard

Pentatomidae) adults and juveniles (Fig. 17) feed on soft-bodied insects often many times their own size, sucking the contents of their prey with needle-like mouthparts. They are found in the vine canopy and in long-grass inter-rows, and are abundant in Riverland & Sunraysia, feeding on vine moth and LBAM larvae (Altmann & Weppler, unpublished data). PREDATORY THRIPS *Haplothrips victoriensis* (Thysanoptera: Phlaeothripidae) (Fig. 18) is a tiny predator (2-3 mm) whose adults and larvae feed on grape rust mite and TSM [41]. It over-winters in bark fissures on vine canes, and under the bark of older wood. Eggs are often laid under the outer scales of dormant buds, where young larvae feed on rust mite. Very important predators of pest mites are of course PREDATORY MITES (Phytoseiidae) (Fig. 19) [1].

How much does each beneficial contribute to pest control?

We do not know exactly how much each beneficial species contributes to pest control in Australian vineyards. No detailed feeding evaluation of vineyard predators (on vineyard pests) has ever been done in Australia, except for some work on predatory mites, and early ▶

studies in 1970-'80s [23, 41, 42]. The impact of mealybug parasitoids was also not studied in Australia, nor were parasitoids of LBAM (larvae & pupae) investigated except very recently [45], and in two early studies [46, 47]. But the key role of the wasp *Dolichogenidea tasmanica* in LBAM control is well established by New Zealand research. Research in Australia has concentrated on the LBAM egg parasitoid *Trichogramma* sp. (>20 scientific papers published since 1990s), even tough species of *Trichogramma* can only control LBAM eggs (not caterpillars or adults), and LBAM egg-masses are often not parasitised in high numbers until after harvest [48]. Furthermore, *Trichogramma* wasps are highly sensitive to wettable sulphur [49], and parasitised egg-masses are subject to predation. New scientific techniques (infra-red imaging) are making direct quantitative field studies on the impact of predators far easier and cheaper than ever before, and it is time for such assessments in Australia; most urgently in relation to mealybugs. Yet, in conserving one beneficial species, we also conserve many others, and so it is possible to implement IPM in vineyards, while research to elucidate the exact role of key beneficials is underway.

Enhancing beneficials by inter-row management

Alternate row mowing of grass inter-rows can be used to provide pollen and shelters for beneficials. More sophisticated, yet cheap and simple to apply, direct-drilling of buckwheat strips in some inter-rows (Fig. 20) provides high quality nectar and pollen for beneficials [50-53], and has been extensively researched in New Zealand vineyards. Results of this research are available to growers, so please contact us for precise information on how to do this and for other IPM methods to enhance beneficials.

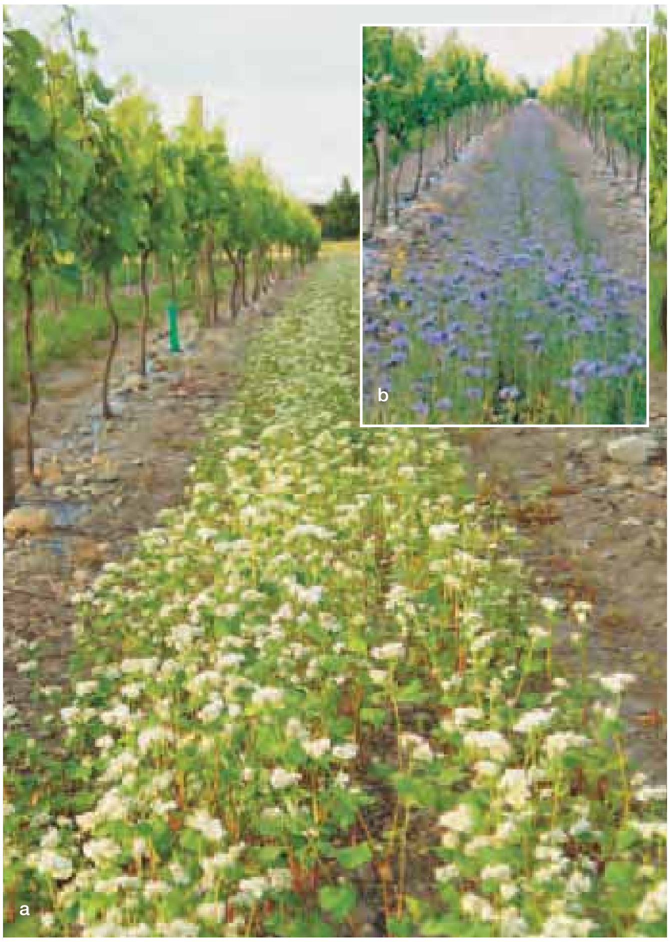

Fig. 20. (a) Buckwheat, (b) Phacelia inter-row strips provide nectar & pollen for parasitoids, and for predators (e.g. hover flies or some green lacewings) whose adult life stages feed on nectar and pollen. (© J.Dufour, Waipara Hills Vineyards, New Zealand). Photo taken by Professor Steve Wratten's associates as part of joint research.

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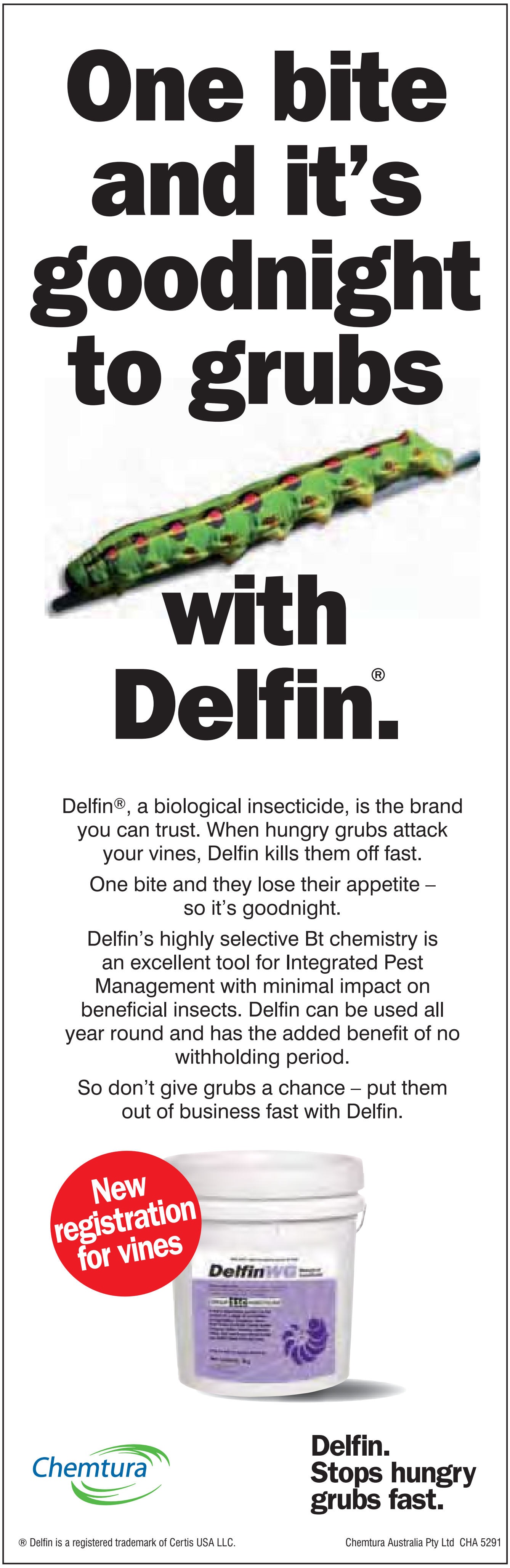

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Beneficial insects in vineyards:

Parasitoids of LBAM and grapevine moth in south-east Australia

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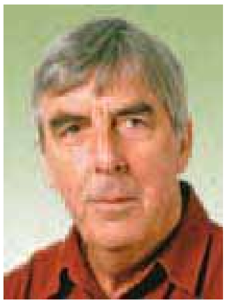

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Introduction

Naturally-occurring biological control of pests is an important ecosystem service, provided by nature free of charge to human agriculture. It contributes greatly to the control of many potential pests, even in highly modified agricultural landscapes, particularly where IPM or organic farming practices are used[1-3]. The value of pest and disease suppression by natural enemies in crops worldwide is conservatively estimated at US$100 billion per year[4,5]. Beneficial insects are important providers of biological control in vineyards. An overview of vineyard predators was published in *The Australian & New Zealand Grapegrower & Winemaker*, September 2006[6]. Here we continue by giving an overview of parasitoids of LBAM (lightbrown apple moth: *Epiphyas postvittana*), and of grapevine moth (*Phalaenoides glycinae*) found in vineyards in/near the Yarra Valley over two growing seasons 2003-05; (GWRDC project MU LTU 02-01). All vineyards were in close proximity to large blocks of native remnant vegetation. We provide photographs, graphs summarising seasonality, an overview of knowledge on key species, and show two ways beneficials may be effectively enhanced by vine inter-row management. Wasps and flies parasitising LBAM eggs, larvae, pupae, and vine moth larvae are featured. An excellent account of the beneficial species complex controlling grapevine moth was published elsewhere[7].

The most detailed study of LBAM parasitoids in Australia to date[8], carried out intensive rearing of LBAM from the Coonawarra region during 2002-05, and recorded many more species of parasitoids than are presented here, from the Yarra Valley. A number of these species are likely to be common across the range of LBAM, while the overall species composition in each region may vary. Our knowledge in Australia is currently restricted to a few areas where detailed research was undertaken, and the full potential of parasitoids available for the control of LBAM is yet to be realised.

The beneficial species complex of LBAM

Specialist parasitoids together with generalist (multi-feeding) predators[6] form the beneficial species complex associated with LBAM. These beneficials undergo changes in abundance over the growing season (Fig. 1), each contributing to a greater or lesser degree to overall pest control. LBAM parasitoids were abundant later in the season. In early spring and summer, insect ▶

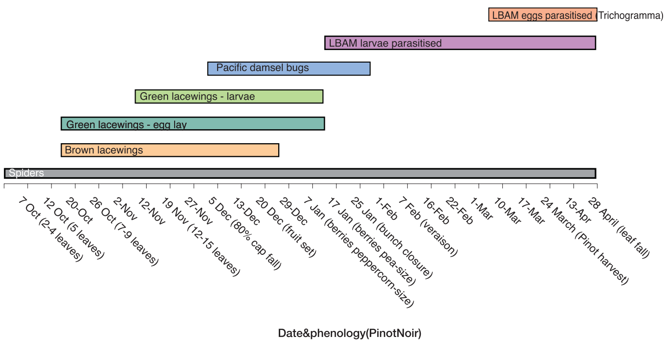

Fig. 1. Approximate periods of high abundance of beneficials in vineyards studied in 2003-05 growing seasons (predatory mites, mealybug and scale parasitoids not included)

predators and spiders were more abundant (Fig.1)[6]. Periods of high abundance are of interest to us, because they indicate when each beneficial is likely to contribute the most to pest control, and when use of pesticides toxic to beneficials is going to be especially detrimental. It is worth noting, for example that the new high rates of wettable sulphur (6 kg/ha) against powdery mildew, novel insecticides against LBAM, and insecticides against mealybugs are all used up to *c.* fruit set, a time of high green lacewing, brown lacewing, and damsel bug abundance. Therefore should any off-target toxicity apply, these sprays are in fact well positioned in time to negatively affect these beneficials and their seasonal contribution to pest control; for example of mealybugs. It is also important to (1) note that the beneficial species complex as a whole delivers pest control (rather than one key 'stand alone' beneficial), and (2) to move away from the previous Australian wine industry emphasis on only LBAM egg parasitoids *Trichogramma* sp. The moment a LBAM caterpillar hatches from the egg, it is beyond the reach of *Trichogramma*, then predators[6], and wasps and flies parasitising LBAM larvae and pupae contribute to control; some predators also feed on LBAM eggs[8-10] (Horne; Altmann & Weppler; unpublished data). All these vineyard beneficial species are native to Australia. They inhabit native vegetation, and can also move into and prosper in agricultural ecosystems. Their numbers are thus dependent on both what happens inside, as well outside the vineyard. Spraying pesticides that kill these beneficials has an immediate visible effect on beneficial numbers within a vineyard, but with such factors out of the system, the effect of factors beyond the vineyard can be very important. Vineyard inter-row management to enhance beneficials can also be very important.

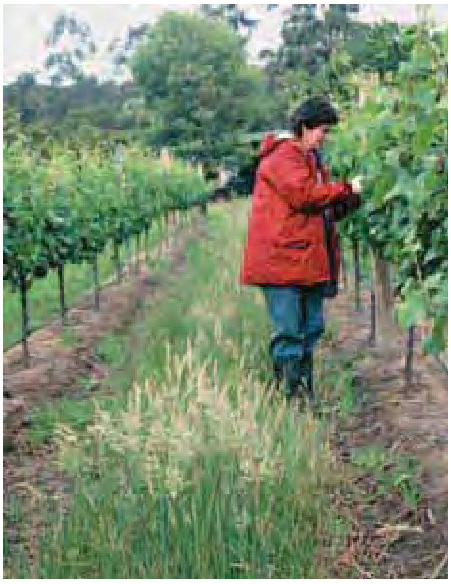

Fig. 2. Alternate row mowing of grass inter-rows (providing pollen and shelter for beneficials); weekly monitoring of pests & beneficials (direct observation of the vine canopy: Ms Vicki Carter) (©M. Bernard)

Enhancing beneficials inside the vineyard

A key step in conserving naturally present biological control agents in vineyards is the elimination (or minimal use) of pesticides toxic to beneficials. Following that the easiest to implement measures apply to vine inter-row management. Parasitoids of LBAM, and predators such as predatory mites[11] and insect predators whose adult life stages feed on nectar and pollen (e.g. hoverflies, and some green lacewings) may be enhanced in vineyards by providing them with pollen, nectar, and shelter in vine inter-rows. Simple alternate row mowing (allowing grass to flower in every second row) (Fig. 2), provides pollen and shelter from heat and low humidity. When long grass is cut, it is used as mulch on bare ground under-vine strips, reducing water evaporation losses, and improving habitat for ground-dwelling beneficial insects and spiders. Nectar provision for beneficials may be further enhanced by more sophisticated, yet cheap and simple to use direct-drilling of buckwheat strips in some inter-rows (Fig. 3ab) to provide high quality, readily available nectar. Nectar provision using buckwheat strips has been extensively evaluated in New Zealand in regards to a key Australian native LBAM larval parasitoid (*Dolichogenidea tasmanica* - Fig. 5)[12-17], and has been successfully extended into vineyard practice there. In New Zealand vineyards, the use of flowering buckwheat in one row in 10 reduces leafroller populations to below economic thresholds, and a whole wine region is adopting these and other practices, using native and non-native plants. Buckwheat nectar is also expected to enhance other parasitoid species such as parasitoids of mealybugs, vine scale, and vine moth. Please contact us for precise information on

Fig. 3. (a) Buckwheat, and (b) phacelia (*Phacelia tanacetifolia*) vine inter-row strips provide high quality nectar and pollen for parasitoids, and for predators whose adult life stages feed on nectar and pollen. (©Jean-Luc Dufour, Waipara Hills Vineyards, New Zealand)

buckwheat use, and for other IPM methods to enhance beneficials. Workshops and training in beneficial recognition are also available. New Australian research also identified white alyssum (*Lobularia maritima*) as a valuable nectar source for *Trichogramma carverae*[18]. The promising potential of native plant species as a nectar source is under investigation in New Zealand, and needs to be investigated in Australia.

Beyond-the-vineyard initiatives

Beyond-the-vineyard factors, such as the distance of a vineyard from a remnant native vegetation source of beneficials, and the size of the remnant may be very influential in determining beneficial presence in crops. A region-wide beneficial enhancement initiative is now under way in a wine growing region in New Zealand; see www.waiparawine.co.nz/index.cfm/research/greening_waipara.html, and www.lincoln.ac.nz/story13772.html. Combining Landcare re-vegetation initiatives with research into beneficial enhancement in Australia, could provide environmental, cost saving and marketing benefits to Australian grapegrowers in the future.

Sampling methods and limitations

Graphs presented here show trends found in four IPM-managed vineyards over two growing seasons 2003-05 in close proximity to large blocks of remnant native vegetation. Seasonal population changes of beneficials still need to be studied over a longer period, and in other regions; a task beyond the scope of this project. In dynamic, living ecosystems, numbers, peak times, and individual species can vary between sites, regions and years. We present results and their interpretation given those constraints. Full scientific data are being prepared for publication elsewhere.

Field counts of parasitoid pupae and larvae showing parasitism were made by direct observation of the vine canopy. All parasitoid pupae and abnormal LBAM larvae were collected, reared to adult emergence in the lab, and identified to species. 100 randomly selected shoots (replicated 3-6x; n = 3-6) were examined from tips, both sides of leaves, one fruit cluster, to 10cm cordon sections below each shoot; 300-600 shoots were checked weekly in each vineyard (7 October-28 April); four vineyards were sampled 2003-05. Scoring larval parasitism in the field is fast and well suited to routine IPM monitoring, but it underestimates parasitism[19] as only parasitoid cocoons can be scored (parasitised larvae generally show no superficially visible symptoms). This was compensated by the frequency (weekly) of sampling, to sufficiently indicate peak seasonal activity. The alternative (collecting large numbers of LBAM larvae, rearing these to adult emergence, and scoring % parasitism), and the study of mealybug and scale parasitoids, were beyond the scope of ▶

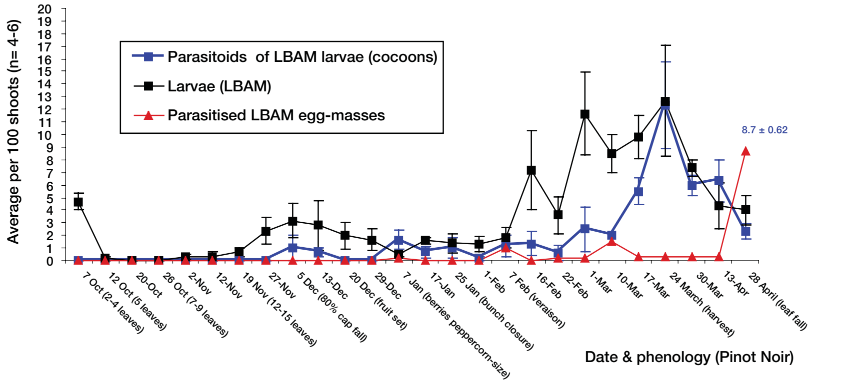

Fig 4. Parasitoids of LBAM larvae, LBAM larvae (non-parasitised) & LBAM egg- masses parasitised by *Trichogramma* (Yarra Valley 2004-05): average per 100 vine shoots (± S. E.)

this project, focused primarily on predators. LBAM egg parasitism was scored as above; by weekly counts of all LBAM egg-masses (emerged; freshly laid; parasitised). All parasitised egg-masses were collected, reared until emergence, and wasps were identified to genus. High LBAM numbers were recorded in the cooler (2004-05) growing season. For pesticide use in study sites see[6].

Parasitoids of LBAM larvae and pupae

Eight wasp species parasitising LBAM larvae were found in the Yarra Valley vineyards studied; they are shown collectively (Fig. 4, page 21). They were found parasitising LBAM later in the season (from *c*. December/January) and were most abundant from about mid-March, increasing in direct proportion with LBAM larvae (Fig. 4). Their main contribution to LBAM control was late in the season when only BT sprays are available for use. However, one vineyard studied had low numbers of these parasitoids.

The two wasps which most commonly parasitised LBAM larvae were: (A) *Dolichogenidea tasmanica* (Hymenoptera: Braconidae) (Fig. 5a-c) parasitising young (1-2nd instar) larvae, and (B) *Goniosus sp*. (Hymenoptera: Bethylidae) (Fig. 6a-c), parasitising 3-4th instar larvae. Adults of these wasps are not easily recognised by the non-specialist, but not so the cocoons, which are spun by ▶

Fig. 5. The most common parasitoid of LBAM larvae (Yarra Valley) *Dolichogenidea tasmanica*: (a) adult wasp (©C. Stephens, University of Adelaide), (b-c) cocoon before adult wasp emergence ('white rice grain') (©Semeraro & Bernard)

Fig. 6. A common parasitoid of LBAM larvae (Yarra Valley) *Goniosus* sp. (a) adult wasp (© C. Paull, University of Adelaide) (b-c) cocoons ('brown rice grain'); (b) showing dead LBAM larva's head capsule alongside wasp cocoons (© Semeraro & Bernard)

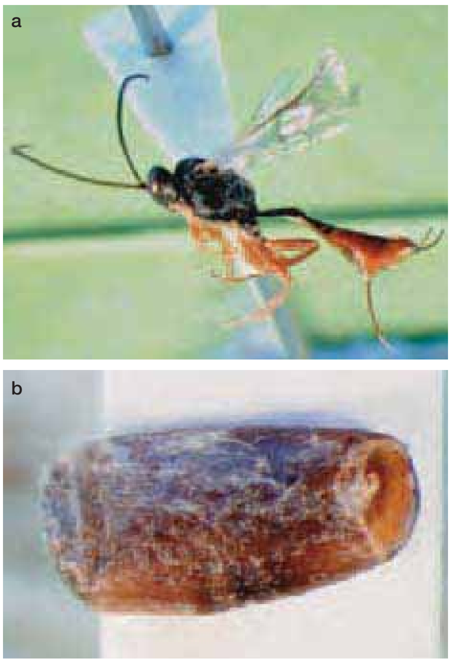

Fig.7 Parasitoid of LBAM larvae (Yarra Valley) *Eriborus epiphyas* (a) adult, and (b) cocoon resembling 'a wild rice grain' (© L. Semeraro)

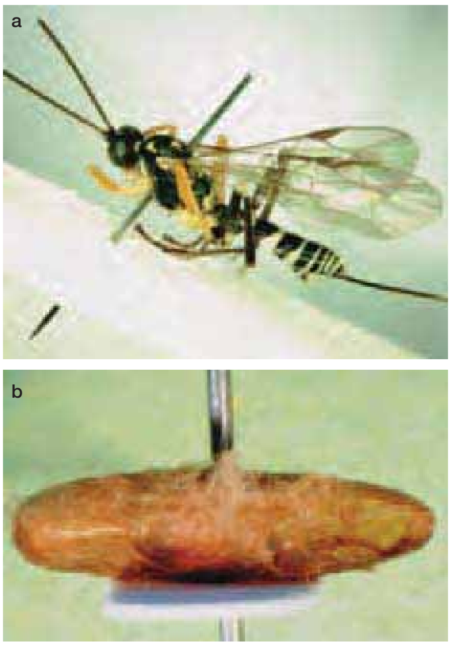

Fig. 8 Parasitoid of LBAM larvae (Yarra Valley) *Phytodietus celsissimus*: (a) adult wasp (© C. Paull, University of Adelaide), (b) cocoon resembling 'a wild rice grain' (© L. Semeraro)

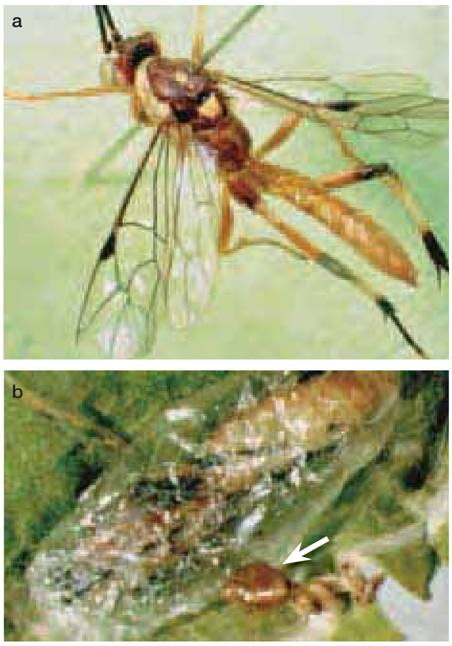

Fig. 9 Parasitoid of LBAM larvae (Yarra Valley) *Australoglypta latrobei* (a) adult wasp , (b) white silken cocoon, with dead LBAM larva's head capsule alongside (© L. Semeraro)

immature wasps on emergence from the dead LBAM larva. The cocoons can be easily recognised by their colour and shape: (A) appears rather like a thin long-white rice grain (Fig. 5b-c) usually found alone; (B) appears rather like a short-brown rice grain of normal size and is usually found in small clutches (Fig. 6b-c). The remains of the dead LBAM larva's head capsule are often found alongside the cocoons (Fig. 6b). (B) is known from Victoria, SA, NSW, ACT, Tasmania[8-10]. Two species of this genus parasitise LBAM, one of which is naturalised in New Zealand[20]. (A) is known from Victoria, South Australia, Tasmania, Queensland and ACT[21], is abundant in Coonawarra vineyards[8], and parasitised about 30% of LBAM larvae in a study near Mildura[22]. It was introduced to New Zealand where it is now the most abundant leafroller parasitoid in vineyards; widely studied to further enhance its abundance and rates of parasitism[13,15-17].

Other wasp species parasitising LBAM larvae were less common. *Eriborus epiphyas* (Fig. 7ab) (Hymenoptera: Ichneumonidae) so far only confirmed here from the Yarra Valley, and from Coonawarra region [8]; and *Phytodietus celsissimus* (Fig. 8ab) (Hymenoptera: Ichneumonidae) recorded only from Victoria, NSW, and Tasmania. Both have dark brown to purple cocoons, colored rather like grains of wild rice (Fig. 7b, 8b). The large wasp *Australoglypta latrobei* (Fig. 9ab) (Hymenoptera: Ichneumonidae) can be recognised by its large delicate silken cocoon, spun on emergence from the host[23]. Two other wasps *Meteorus sp.* (Hymenoptera: Braconidae), *Gambrus sp.* (Hymenoptera: Ichneumonidae), and two fly species (Diptera: Tachinidae) (Fig. 10ab), one common in unsprayed grapevines near Mildura[22], also parasitised LBAM larvae. The wasp *Brachymeria teuta* (Hymenoptera: Chalcididae) parasitised LBAM pupae.

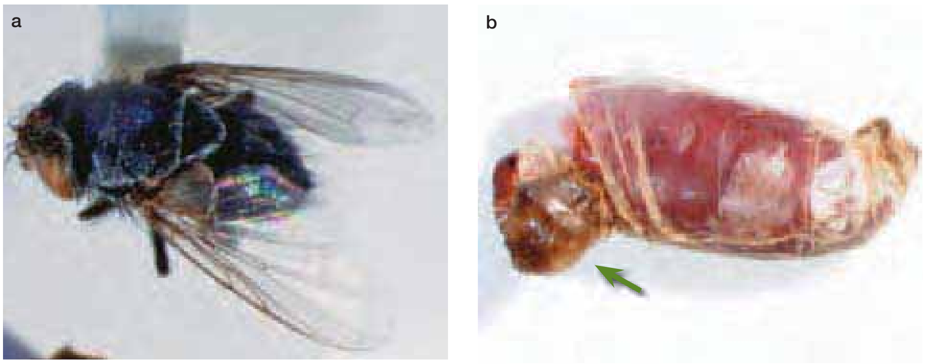

Fig. 10 Parasitoid of LBAM larvae (Diptera: Tachinidae) (a) adult fly, (b) empty cocoon after fly emergence, with dead LBAM larva's head capsule shown near the exit hole (© L. Semeraro)

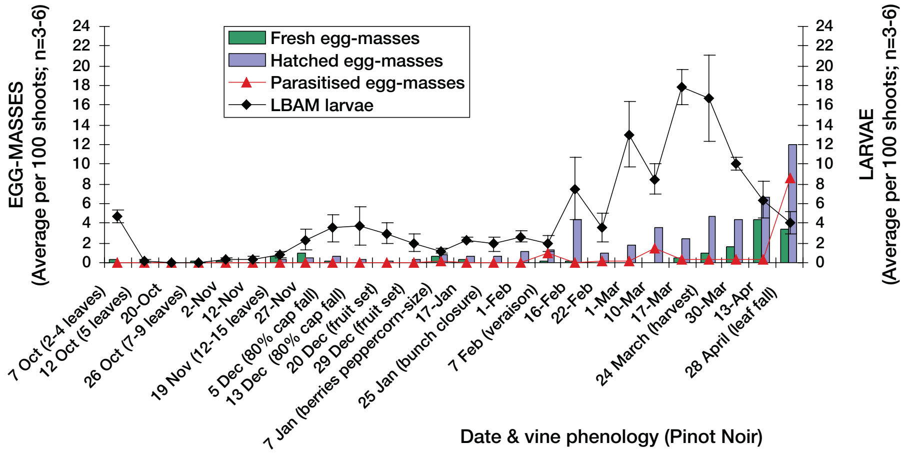

Fig. 11(a) LBAM egg-massess parasitised by *Trichogramma* sp., compared to non-parasitised egg-masses (freshly laid & hatched), and to LBAM larvae: Site I - Yarra Valley, Victoria 2004-05

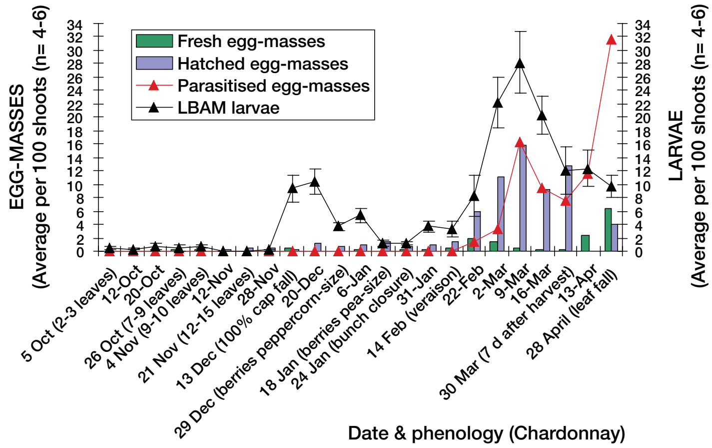

Fig. 11(b) Site II - Hoddles Creek, Victoria 2004-05

LBAM eggs parasitoids – *Trichogramma* sp.

When considering LBAM parasitism, the egg parasitoid *Trichogramma* sp. (Hymenoptera: Trichogrammatidae) may first come to mind. Particularly in Australia where *Trichogramma* sp. has been by far the most studied of all vineyard beneficials in recent years, and the most promoted in wine industry extension. However, *Trichogramma* wasps are naturally limited in their ability to control LBAM; they can only attack LBAM eggs (no other life stage), and both parasitised and non-parasitised eggs may be eaten by predators. Furthermore, seasonality data from many vineyards show poorly parasitised LBAM eggs for most of the growing season[8] (Horne; Altmann; unpublished data), even where recognised disruptive chemical sprays were not used[24]. We found no parasitised LBAM egg-masses in all sites for most of the growing seasons 2003-05; first egg parasitism was only recorded *c.* veraison, and high parasitism did not occur until *c.* mid-March (Fig. 4, 11ab). Many LBAM eggs in all study sites developed into caterpillars and were thus no longer accessible to bio-control by *Trichogramma* (Fig. 4, 11ab). The lack of parasitism is considered to be due to biological and ecological constraints[24], and may also be linked to high sensitivity to wettable sulphur[25]. All vineyards studied here used lower than industry average rates and concentrations of wettable sulphur. We suggest that the recent Australian wine industry focus on *Trichogramma* sp. in both research and wine industry extension as a 'stand alone' bio-control agent has been over-emphasised. However, late in the growing season (from *c.* mid-March) high numbers of LBAM egg-masses were parasitised (Fig. 11ab), suggesting *Trichogramma* can be important near harvest, and in reducing the over-wintering LBAM population, while playing a minor role in vineyard pest suppression during the rest of the growing season. Only when *Trichogramma carverae* wasps were mass-released in vineyards was a large percentage of LBAM egg masses parasitised earlier in the season[26](Altmann; unpublished data).

Grapevine moth parasitoids

One species parasitising grapevine moth larvae (late instars) was collected in the Yarra Valley *Euplectrus agaristae* (Fig. 12ab) (Hymenoptera: Eulophidae); with many tiny wasps emerging from each parasitised caterpillar. This species has also been recorded from Coonawarra vineyards in SA[7].

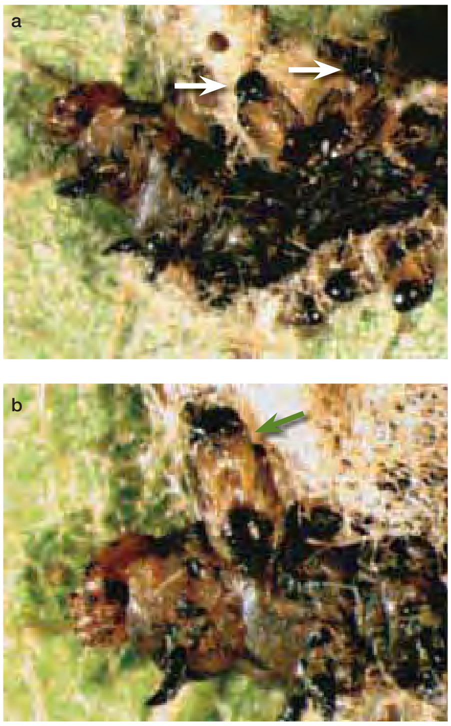

Fig. 12 Parasitoid of grapevine moth larvae *Euplectrus agaristae* (Yarra Valley): (a) dead, parasitised larva and multiple wasp pupae, just before adult wasp emergence; (b) wasp pupa-detail (© Semeraro & Bernard)

Acknowledgements

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The influence of adjacent vegetation on the abundance and distribution of natural enemies in a vineyard

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Vegetation exists adjacent to vineyards for a variety of reasons. Vegetation may be remnant, or planted to provide protection from chemical drift, corridors for wildlife, shelter for stock, treatment of soil salinity or removal of waste water by providing a soak with associated transpiration. By providing resources such as shelter, overwintering sites and food sources, adjacent vegetation can influence invertebrates present not only in the vegetation itself, but also in the vineyard. As these invertebrates will include natural enemies relevant to control of pests in grape production, adjacent vegetation has the potential to lead to increased numbers of natural enemies.

A number of natural enemies of LBAM, scale, mealybugs and pest mites for example are thought to benefit from food sources and shelter available in remnants and shelterbelts. These include parasitoids, lacewings, predatory mites, predatory bugs and spiders. At the same time, there are reports of vegetation increasing pests (Coventry *et al.* 2004), so it is important to determine that there are no increases in pests associated with vegetation.

We have collected data in a Yarra Valley vineyard with remnant eucalypt vegetation on one boundary and a shelterbelt incorporating flowering shrubs on a second side. The remnant consisted of a messmate Eucalyptus canopy with a shrubby understorey of common heath (*Epacris impressa*), Hazel (*Pomaderris aspera*) and clematis and the shelter belt consisted of grasses, flowering shrubs (red flowered paperbark, *Melaleuca hypericifolia* (Myrtacea), heath teatree, *Leptospermum myrsinoides* (Myrtacea), black wattle *Acacia mearnsii* (Fabaceae) and *Erica lusitanica* (Ericaceae) and low trees - swamp gum (*Eucalytus ovata*) and blue gum (*Eucalyptus globulus*). We hypothesised natural enemy abundance would be lower in the interior of the vineyard and higher near adjacent vegetation. To investigate effects of this adjacent vegetation on abundance and distribution of natural enemies, we sampled with yellow sticky traps (for the canopy) and pitfall traps (for ground level) at 100 points throughout the vineyard and used spatially explicit mapping techniques to establish patterns of natural enemy abundance across a season.

Analyses focussed on organisms collected in sufficient numbers that were likely to act as natural enemies of pests affecting grape production. Eight groups of beneficials were identified from the sticky traps sampling the canopy (including spiders, lacewings, bugs, ladybird beetles, predatory flies and many species of parasitoids, including Trichogramma) as well as 13 groups from the pitfall traps sampling ground active animals (including spiders, predatory mites, larval lacewings and parasitoids). We found 50 different species of parasitoids but here 'parasitoids' are considered as a group because there is still much to be learnt about their role in vineyards. We know they are important natural enemies of LBAM, scale and mealybugs but many interactions between pests and parasitoids remain to be uncovered. More than 8183 beneficials were sorted and analysed to assess if the abundance and distribution of natural enemies within a vineyard was influenced by the vegetation at the margins. First spatial analysis was applied to the counts at each sampling point to determine if the distribution was non random using Spatial Analysis by Distance IndicEs or SADIE (http://www.rothamsted.bbsrc.ac.uk/pie/sadie; Perry, 1998), then the points were mapped to visualise the distributions using a mapping program (SURFER ver. 8.05 Golden Software®).

Our results showed the presence of vegetation adjacent to the vines increased the numbers of natural enemies in the vineyard. As indicated in the figure, remnant vegetation increased the abundance of ground spiders in particular. Vines adjacent to the shelterbelt which included flowering shrub species had relatively higher numbers of predatory mites, predatory and parasitic flies and parasitoids. Higher numbers of Trichogramma (egg parasitoids of LBAM) were associated with both the shelterbelt and the remnant block. There were also two negative effects of shelterbelts detected on beneficials, in that adjacent vines had lower numbers of ladybird beetles and canopy spiders. As evident from patterns seen in the figure, increases in the relative abundance of beneficials extended well into the vineyard. For the parasitoids from pitfall traps, for instance, numbers were still higher 100m away from the shelterbelt. Similarly, for ground spiders, differences were detected 50m away from the remnant vegetation. These results suggest that vegetation can exert effects on numbers of natural enemies well away from the vegetation itself.

To determine if this change in natural enemy abundance due to adjacent vegetation had a direct impact on pest control, we placed LBAM egg masses in the vineyard. LBAM egg masses laid on plastic cups were placed at the sampling points in the vineyard on 1 February for five days and a second batch of eggs was placed outside on 6 February for five days. When collected, cards were scored for egg masses lost due to predation. The remaining eggs were kept at 25°C until parasitoids emerged and these were identified (Glenn *et al*. 1997). The percentage of egg masses lost to predation and parasitism were calculated for each sampling point. Parasitism was calculated as the percentage of the egg masses remaining after loss by predation. On collection, 40% of egg masses were missing (due to predation). Of the remaining egg masses, 57 % were parasitised and two species of Trichogramma were recovered from the parasitised eggs (*T. funiculatum* and *T.* sp. *x*). Predation ▸

was not affected but parasitism by Trichogramma wasps was higher adjacent to remnant vegetation and was correlated to the numbers of Trichogramma collected in yellow sticky traps (figure 1).

The taxa increased by adjacent vegetation - predatory mites, spiders, staphylinids, lacewings, predatory flies and a wide range of parasitoids including species of Trichogramma - all have a potential role as natural enemies in vineyards. Staphylinids or rove beetles are known to be important generalist predators. The wide host ranges of spiders means not only they will consume a variety of pests but also they can exist in high numbers and be available to prey on pests like LBAM which appear sporadically throughout the season (Danthanarayana 1975). Lacewings are voracious predators of mites, mealybugs and LBAM eggs. The range of parasitoids known to attack vineyard pests (Thomson and Hoffmann 2006) is constantly expanding (e.g. Paull and Austin 2006). Predatory mites contribute to control of eriophyoid mites, flies are known to parasitise LBAM, others parasitise mealybugs and possibly scale (Waterhouse and Sands, 2001) and it has been suggested that still others (hoverfly larvae) may eat LBAM caterpillars. However the two groups of natural enemies that were at a lower abundance near the shelterbelt (canopy spiders, ladybird beetles) may also contribute to pest control.

Direct evidence for a positive effect of vegetation on pests came from the parasitism of LBAM eggs. The relatively higher parasitism rate near remnant vegetation and positive correlation between parasitism and numbers of Trichogramma responsible for the egg parasitism in this vineyard suggests that high numbers of natural enemies have positive effects on pest control. On average, at sampling points close to the vegetation, the number of LBAM larvae would have been reduced from 1000 to 400 by the action of Trichogramma alone. In contrast to the parasitism effects, we found no positive impact of vegetation on egg predation, which may reflect the inconsistent effects of vegetation on different groups of generalist predators.

Why did vegetation influence some groups? Vineyards can be recolonised from perennial habitats by the groups represented here: spiders, syrphids, staphylinids, parasitoids, predatory mites. Many spider species colonise crops by drifting through the air on threads of spider silk (ballooning), staphylinids possess a high movement rate (through flight or passive wind dispersal). Nectars are significant sources of nutrition for most adult predatory mites, lacewings, parasitoids, predatory and parasitic flies and staphylinids. Adjacent flowering plants have frequently been shown to increase natural enemies and biological control in a range of

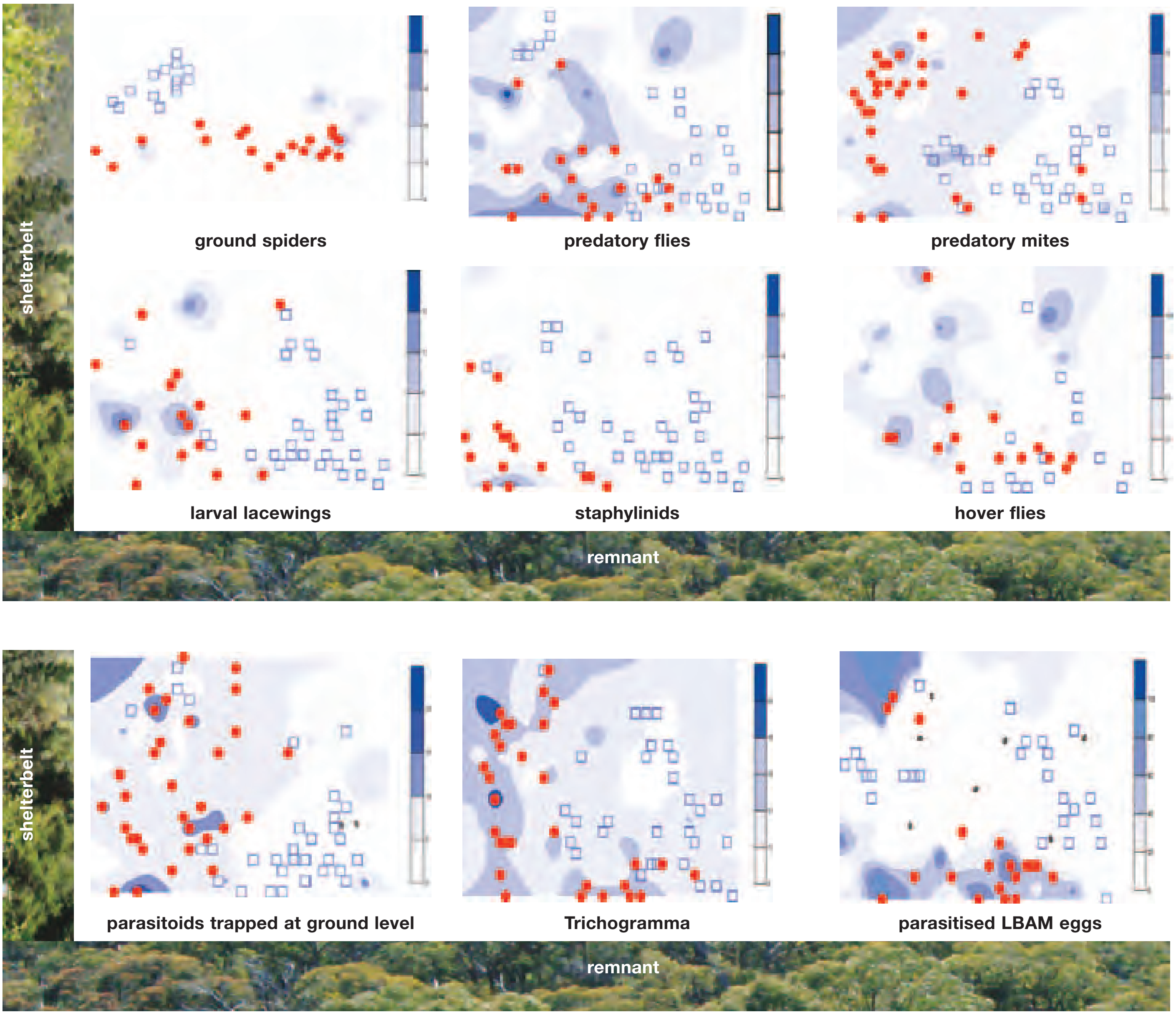

Fig. 1. distribution of natural enemy groups captured in a vineyard bordered by remnant vegetation and a shelterbelt. ● indicates point with high numbers and □ indicates point with low numbers. Shading shows distribution over entire vineyard.

crops including vineyards (Williams and Martinson, 2000) and the results for LBAM egg cards reinforced the notion that increased control can occur adjacent to vegetation.

What about other groups not affected or negatively affected by vegetation? The fact that adult lacewings were unaffected by vegetation unlike larval lacewings may reflect the higher movement rates of adults, while the positive effect of vegetation on ground spiders but not on canopy spiders may also reflect relative rates of movement of these groups. Spiders caught in the canopy may be more able to move around within the vineyard so be less likely to show effects of adjacent vegetation. It is not clear why numbers of canopy spiders and ladybird beetles were relatively more abundant away from vegetation -perhaps there are competitive interactions among generalist predators.

These results indicate the abundance and distribution of vineyard natural enemies is influenced by adjacent vegetation and there are direct beneficial effects on the control of a moth pest. The conservation of remnant vegetation and planting of shelterbelts around vineyards may have direct economic benefits in terms of pest control. We show the abundance of several groups of natural enemies and parasitism of moth eggs are increased adjacent to vegetation.

Further work is required to discover aspects of vegetation which are important to the different groups, involving a detailed spatial analysis of other vineyards and surveys of large numbers of vineyards with different types of adjoining vegetation. The data collected here suggests that existing vegetation and revegetation can contribute to pest control by natural enemies with the potential to reduce chemical applications, contributing to both increased economic and environmental sustainability of the wine industry. This is a step along the way to identify means to encourage environmentally sensitive targeted crop protection measures.

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Introductory workshops on biodynamics

Biodynamic Agriculture Australia has been conducting a number of one-day introductory workshops throughout NSW.

The use of biodynamics to improve and enhance soil fertility, animal health and farm profitability was the focus of four one-day workshops in central and northern NSW at the end of October and early November, 2006.

The workshops were presented by biodynamic educator, Hamish Mackay. "This introduction to biodynamics includes soil fertility, the soil food web, managing plant and animal health, weeds and pests. Participants will learn about making on-farm inputs such as biodynamic compost, liquid fertilisers, tree paste and weed teas. They will see what the biodynamic preparations are and how to prepare, store and use them on farm," said Mackay.

The last of the one-day workshops will be at "Billabong", Inverell, hosted by Glen Morris, on 9 November.

For further information and bookings contact Biodynamic Agriculture Australia on 02 6655 0566, online at www.biodynamics.net.au or email: bdoffice@biodynamics.net.au.

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