EcoVineyards
GROWING RESILIENCE NATURALLY

BEST PRACTICE MANAGEMENT GUIDE

ON FUNCTIONAL BIODIVERSITY IN AUSTRALIAN VINEYARDS

by Dr Mary Retallack, Retallack Viticulture Pty Ltd

Wine Australia

retallack viticulture

ACKNOWLEDGEMENTS

The EcoVineyards series of best practice management guides (BPMGs) and support materials were developed by a team of subject specialists led by Dr Mary Retallack, Retallack Viticulture Pty Ltd for the National EcoVineyards Program.

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Cover photographs (clockwise from top left): *Leptospermum continentale*, prickly tea-tree in flower in the Henschke vineyard, Lenswood, South Australia; microbat boxes installed in stringybark open forest, Crafers West; flowering saltbush at the Starrs Reach Vineyard in the Riverland, South Australia; *Coccinella transversalis*, transverse ladybird beetle, at the Oborn vineyard, Coonawarra; *Vittadinia* sp. New Holland daisy in Morella Vineyard, Clare Valley, and *Accipiter fasciatus*, brown goshawk, Margaret River, Western Australia [Photos: Mary Retallack]

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For more information about the National EcoVineyards Program please visit www.ecovineyards.com.au

ACKNOWLEDGEMENT OF COUNTRY

ECOVINEYARDS PROUDLY ACKNOWLEDGE THE ABORIGINAL AND TORRES STRAIT ISLANDER PEOPLES, AND THEIR ONGOING CUTURAL AND SPIRITAL CONNECTION TO THIS ANCIENT LAND ON WHICH WE WORK AND LIVE. AS THE TRADITIONAL CUSTODIANS WE RECOGNISE THEIRWEALTH OF ECOLOGICAL KNOWLEDGE AND THE IMPORTANCE OF CARING FOR COUNTRY. WE PAY OUR RESPECT TO ELDERS PAST AND PRESENT AND EXTEND THIS RESPECT TO ALL ABORIGINAL AND TORRES STRAIT ISLANDER PEOPLES.

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ACRONYMS

AMES arthropod-mediated ecosystem services

BPMG best practice management guide

CBC conservation biological control

EI ecological infrastructures

ES ecosystem services

ESG environmental, social and corporate governance

FB functional biodiversity

IPM integrated pest management

IUCN international union for conservation

LBAM light brown apple moth

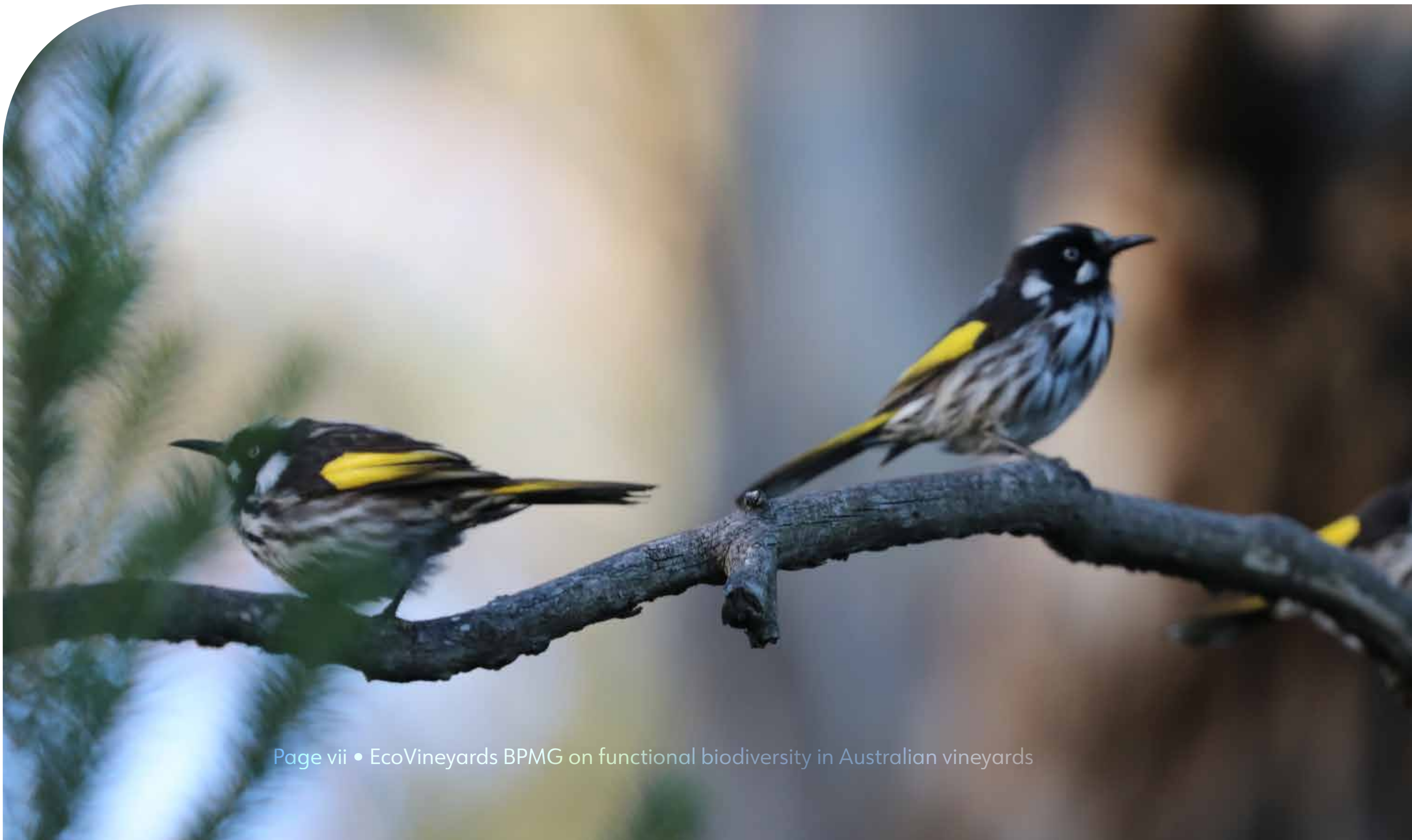
SDG sustainable development goals

SNAP shelter, nectar, alternative prey/hosts, pollen

FUNCTIONAL BIODIVERSITY DEFINITIONS

Term	Definition
Abiotic	An abiotic factor is a non-living part of an ecosystem that shapes its environment. In a terrestrial ecosystem, examples might include temperature, light, and water.
Anthropogenic	Relating to or resulting from the influence of human beings on nature.
Arthropod-mediated ecosystem services (AMES)	Biological control is a key component of arthropod-mediated ecosystem services (AMES), which is used to manage pest insects in production systems, including vineyards. For example, predatory arthropods (insects and spiders) help to regulate populations of pest insects via feeding or parasitism.
Arthropod	Arthropods are invertebrates with segmented bodies and jointed limbs. They include insects, springtails, spiders, and mites. Predatory arthropods contribute to biocontrol of insect pests.
Biotic	Biotic or living components include all living organisms found in the environment, including plants, animals, and microorganisms.
Biodiversity	Biological diversity (or biodiversity) refers to the variety of plants, animals, and micro-organisms that live and interact within an ecosystem. Each species has a niche in the ecosystem and contributes towards its functionality. Biodiversity is typically measured as 'richness' (the number of unique life forms), abundance (number of each life form), 'evenness' (the consistency among life forms) and 'heterogeneity' (the dissimilarity among life forms).
Conservation biological control (CBC)	Conservation biological control is defined as the conservation and augmentation of predatory arthropods that are already in place or are readily available. CBC involves the implementation of practices that protect and enhance the reproduction, survival, and efficacy of natural enemies of pests including planting insectary plants that provide habitat for predatory arthropods.
Consumers	Consumers are organisms that depend on other organisms for food. They take in organic molecules consuming other living things. They include all animals and fungi. • Herbivores consume producers such as plants or algae. They are a necessary link between producers and other consumers. • Carnivores consume animals. Examples include hawks, frogs, and spiders. • Omnivores consume both plants and animals.
Decomposers	When organisms die, they leave behind energy and matter. Decomposers break down the remains and other wastes and release simple inorganic molecules back to the environment. Producers can then use the molecules to make new organic compounds.
Ecological infrastructures (EI)	Ecological infrastructures are defined as any infrastructure within a radius of the order of 150 metres of a farm or vineyard that has an ecological value to the production system and increases the functional biodiversity of the property, such as hedges, grassland, wildflower strips, conservation headlands, stone heaps etc
Ecology	Ecology is the study of how living things interact with each other and with their environment.
Ecosystem	An ecosystem is defined as a biological community of interacting organisms and their physical environment interacting together as a functional unit. An ecosystem consists of all the biotic and abiotic factors in an area and their interactions.
Ecosystem services (ES)	Ecosystem services are the benefits that humans derive from ecosystems. Ecosystem services are often classified into four categories: provisioning, regulating, cultural, and supporting services.

Term	Definition
Endophyte	An endophyte is an endosymbiont, often a bacterium or fungus, that lives within a plant for at least part of its life cycle without causing apparent disease.
Endosymbiont	An endosymbiont is any organism that lives within the body or cells of another organism, most often in a mutualistic relationship, e.g., nitrogen-fixing bacteria (rhizobia) that live in the root nodules of legumes, and bacterial endosymbionts that provide essential nutrients to insects aiding in digestion of food or providing nutrients that are limited or lacking in the diet.
Entomopathogenic fungi	Entomopathogenic fungus can kill or seriously disable insects.
Fauna	Fauna denotes animal life present in a particular region or time.
Fecundity	Fecundity is a measure of the reproductive success of an arthropod or animal. It is usually expressed as the number of eggs or offspring produced by the organism.
Flora	Flora denotes different types of plants.
Functional biodiversity (FB)	Functional biodiversity refers to the set of species that contribute to ecosystem services in an agroecosystem, including the biodiversity that is of direct benefit to the production system (e.g., biological control of pest insects by predatory arthropods found in association with insectary plants). The objective is to ensure optimal production and fruit quality while limiting human interventions in the vineyard. Better plant and soil health promotes a more resilient ecosystem.
Greenwashing	The act or practice of making a product, policy, activity, appear to be more environmentally friendly or less environmentally damaging than it really is.
Habitat	The habitat is the physical environment in which a species lives and to which it is adapted. A habitat's features are determined mainly by abiotic factors, such as temperature and rainfall. These factors also influence the traits of the organisms that live there.
Hedgerow	A hedge or hedgerow is a line of closely spaced shrubs planted and trained to form a barrier or to mark the boundary of an area, such as between neighbouring properties or to limit access to a vineyard for biosecurity purposes (while gaining biodiversity habitat benefits).



Term	Definition
Integrated pest management (IPM)	Integrated pest management is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimise the use of pesticides. Integrated pest management predominantly uses cultural and biological practices with targeted chemical application used as a last resort and only as required to control pests below the economic injury level.
Monoculture	Monoculture is the practice of growing one crop species in a field at a time
Morphospecies	Visually distinct specimens that can be categorised with a number and possible functional group or family prior to being identified to genus and species.
Niche	A niche refers to the role of a species in its ecosystem. It includes all the ways that the species interacts with the biotic and abiotic factors of the environment. Two important aspects of a species' niche are the food it eats and how the food is obtained.
Omnivorous	Feeding on a variety of food of both plant and animal origin.
Polyculture	Polyculture refers to the practice of growing mixtures of different crops together in order to enhance productivity, reduce the need for chemical fertiliser, and provide natural protection against disease and pests.
Producers	Producers are organisms that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. Producers are also called autotrophs. • Photoautotrophs use energy from sunlight to make food by photosynthesis. They include plants, algae, and certain bacteria. • Chemoautotrophs use energy from chemical compounds to make food by chemosynthesis. They include some bacteria and archaea. Archaea are microorganisms that resemble bacteria. Some Archaea are referred to as extremophiles as they can inhabit extreme habitats such as hydrothermal vents, terrestrial hot springs, highly saline, acidic, and anaerobic environments.
Regenerative	While the term 'regenerative' is relatively new, the principles behind the concept reflect practices that some farmers have embraced for generations. It is gaining traction and support due, in part, to the belief that 'regenerative' moves beyond the philosophies of 'do no harm' and sustain what currently exists to one of making things better. While there is no universal definition of 'regenerative agriculture', many believe regenerative approaches include those that help mitigate climate change, improve soil health, restore biodiversity, enhance ecosystems, and contribute to human health.
Resilience	The resilience of a system describes its capacity to reorganise after local disturbance including extreme weather events.
Resource 'bottleneck'	A resource bottleneck is in ecologically relevant period of severe restriction in resource availability. For example, a lower availability of insects, and nectar production during a dry season may limit the population size of species of insectivorous birds and microbats.
Terrestrial	Living or growing on land
Trophic levels	The feeding positions in a food chain or web are called trophic levels. • The first trophic level is a producer or plant. • The second trophic level is a primary consumer. • The third trophic level is a secondary consumer and so on.

EXECUTIVE SUMMARY

The ‘eco’ in EcoVineyards stands for ‘ecological’ vineyard production and regardless of the management system currently employed, we work closely with wine growers across Australia to provide complementary practices with an ecological focus, so we can collectively grow in harmony with nature.

Moving towards more ecologically focused and regenerative production systems is at the heart of the National EcoVineyards Program, and the development of three best practice management guides is a key part of this initiative.

This best practice management guide (BPMG) is part of a series on the following topics:

- soil health in Australian vineyards,
  - Part A (chemical and physical)
  - Part B (soil biology)
- ground covers (including cover crops) in Australian vineyards, and
- functional biodiversity in Australian vineyards – **this guide**.

A summary of each BPMG is included in the table below. These insights are relevant for all wine growing regions in Australia and a broad range of production systems.

Table 1. Summary of the EcoVineyards BPMG series

Soil health	Ground covers	Functional biodiversity
Soil health underpins plant health and vice versa. Soil biology is a key component of pathogen suppressive soils, nutrient cycling, soil structure, carbon storage, and much more. Unfortunately, the living components of soil have often been overlooked when considering soil health. The BPMG on soil health details the tools and resources available to improve soil health in vineyards, with a particular focus on the chemical and physical components in Part A and soil biology in Part B. The BPMG takes growers through the benefits of improving soil health, how to get started, how to assess soil health indicators, setting a benchmark, and monitoring progress over time.	Ground cover plants provide many ecosystem services that ultimately benefit vineyard management and wine grape production. Ground covers include sown ground covers (such as multi-species cover crops), and/or the use of endemic or native species across the entire vineyard floor, including the mid-row and under-vine (natural recruitment, sown and/or planted). The BPMG on ground covers details the tools and resources available to improve ground cover management in vineyards. The BPMG takes growers through the benefits of improving ground cover management, how to get started and how to monitor the outcomes of the changes being made.	Functional biodiversity includes all the fauna found in association with soils and plants (flora) and the interactions between them, for example, predatory arthropods, microbats, insectivorous, and raptor bird species along with all other life found in association. These species provide a range of ecosystem services, including biocontrol of grapevine insect pests. Biodiversity is the variety of plant and animal life. Each species has a niche in the ecosystem and contributes towards its functionality. The resilience of a system describes its capacity to reorganise after local disturbance (including extreme weather events). The BPMG on functional biodiversity details the tools and resources available to improve functional biodiversity in vineyards and how to monitor progress.

WHAT IS A BPMG?

The EcoVineyards best practice management guides (BPMG) are written by a team of experienced research and extension viticulture, agroecology, and ground cover subject specialists.

Each guide is designed as a 'living document' that can be updated as new information becomes available. It provides a summary of both peer-reviewed scientific information and practical insights for wine growers on each topic covered by the National EcoVineyards Program as well as support materials.

The National EcoVineyards Program aims to accelerate adoption and practice change outcomes specified in Wine Australia's Strategic plan 2020 to 2025, specifically:

- to increase the land area dedicated to enhancing functional biodiversity by 10 per cent
- to increase the use of vineyard cover crops and soil remediation practices by 10 per cent.

An ecological approach

The National EcoVineyards Program focuses on the living components of production systems as an underpinning pillar along with soil health, ground covers, functional biodiversity, and the interactions between each.

These ecological and biologically focused principles are complementary to existing practices, help break the cycle of intervention (saving time and resources), and can assist wine growers with their environmental stewardship reporting requirements.

There are many ways to describe wine growing practices with terms like conventional, organic, low input, regenerative and sustainable often used. We prefer not to use the word sustainable, as to 'sustain' in our view is a low bar and cannot be maintained - either we are moving forward or backward.

In some cases, maintaining the status 'quo is' is actually moving backwards, given the dynamic nature of knowledge being unearthed in this field and the huge potential to solve some of the urgent challenges currently being faced by growers. We cannot continue to do more of the same and expect a different outcome.

We advocate for making small changes with an ecological and regenerative focus and then scaling up as a grower observes benefits and gains confidence in practices that are suited to a particular location.

We are conscious of the urgent and dynamic need to future proof production and grow resilience in our viticultural landscapes, while focusing on fruit quality, financial security, and environmental stewardship. To do this, we need to regenerate and move our thinking and production practices forward in harmony with nature. **Together we can make a difference!**

Embracing connection

We embrace the knowledge, wisdom and deep connection to land of First Nations Peoples who have been managing Country and living harmoniously on Australia's lands and waters for more than 65,000 years. Aboriginal Peoples are the original custodians of Country and have a deep connection with and intricate knowledge of not only the land and waters but hold knowledge about biodiversity from long-term observations and management, generational presence, and oral history shared through storylines.

Their wisdom and perspectives provide a meaningful contribution to growing a deeper connection with Country and us. We recognise and acknowledge their respect for Country in our approach of continual learning and appreciation of nature in all its diversity.

Grower knowledge gaps

During events held as part of the National EcoVineyards Program, wine growers were asked to identify knowledge gaps they felt were limiting their ability to implement functional biodiversity practices.

The topics covered everything from which species are important for biocontrol of grapevine insect pests, how to attract predators (arthropods, microbats, and insectivorous birds) into the vineyard, how far can predatory arthropods move, which species of insectary plants to use, where they can be planted and how to manage them within a vineyard setting, which species of insectivorous and raptor birds are common in Australian vineyards, how to monitor for the presence of microbats and create supplementary habitat in the landscape, and how to monitor and quantify the benefits of enhancing functional biodiversity in the vineyard.

This BPMG addresses these questions and provides growers with a 'how-to' guide to progress the functional biodiversity journey in their vineyards.

Ecological restoration and functional biodiversity measures that can be employed to help 'future proof' the production of vineyards in Australia against the effects of climate change and extreme weather events are also explored in the EcoVineyards BPMG series.

Join us in exploring this topic with practical insights from subject specialists.

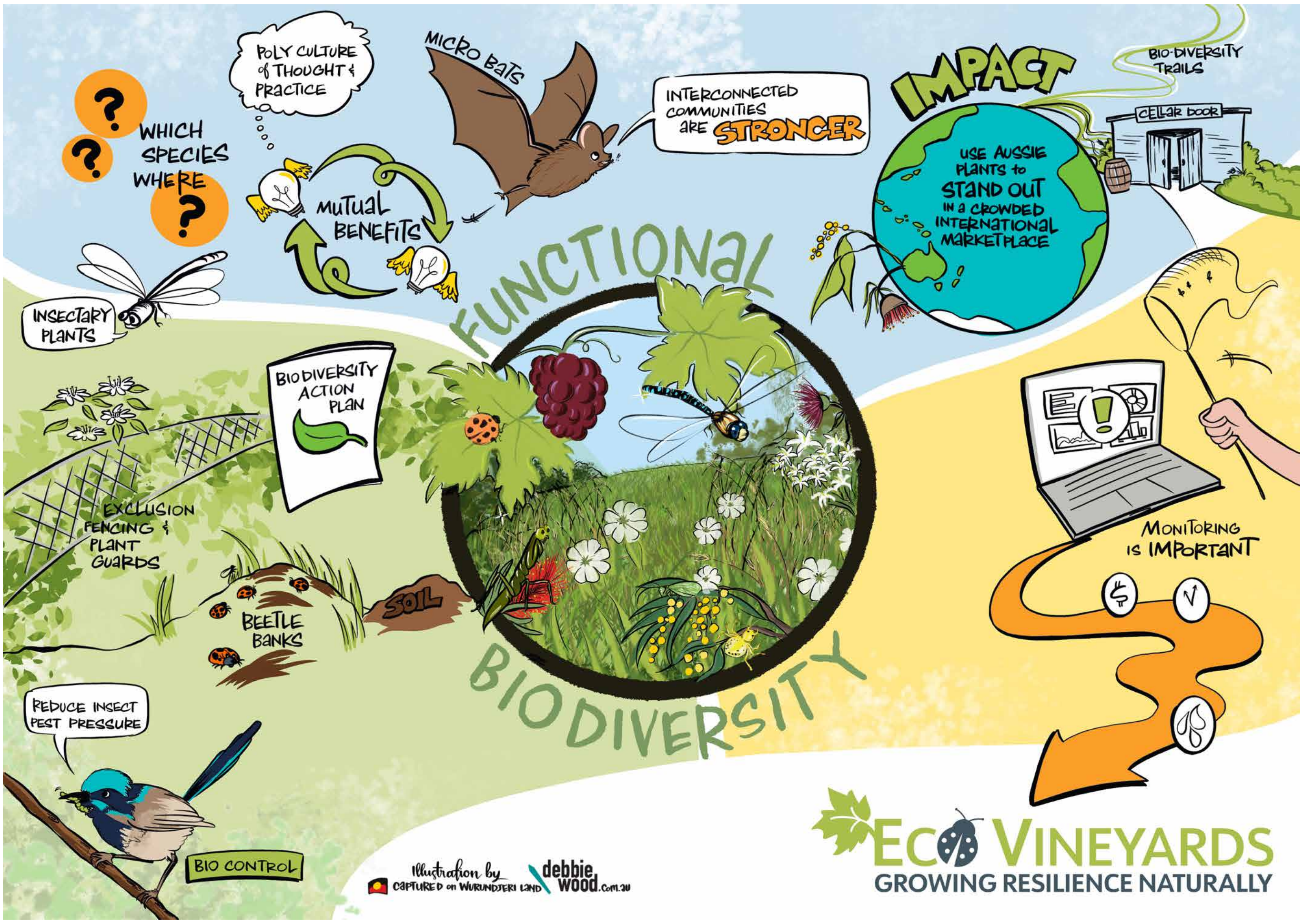


Figure 1. Some of the themes captured within this BPMG on functional biodiversity and, more broadly, in the National EcoVineyards Program [Image: Debbie Wood].

SECTION 1:

NATURE BASED SOLUTIONS

WHAT IS FUNCTIONAL BIODIVERSITY?

Benefits for both wine growers and the environment

- The functional component of biodiversity refers to the set of species that contribute to services in an agroecosystem, that is of direct benefit to the vineyard or production system (e.g., biological control of pest species).
- Biological diversity (or biodiversity) refers to the variety of plants, animals, and micro-organisms that live and interact within an vineyard ecosystem (Cardinale et al., 2012; Wilson and Peter, 1988). Each species has a niche in the ecosystem and contributes towards its functionality.

There are many important reasons to embrace our relationship with nature. We are, of course, a part of the natural world and what we do to nature we do to ourselves!

We will also discover that rather than feeling that we are fighting against nature, ecological solutions hold many of the answers we are looking for to help mitigate two clear threats to the planet, including our capacity to grow wine grapes and, consequently, our way of life.

Many of the impacts we experience are due to:

- climate change, extreme weather events,
- biodiversity decline.

By growing resilience in agricultural systems and embracing ecological solutions, we can grow our response to both challenges and, in doing so, also reduce the unintended consequences of some of our existing viticultural practices (e.g., loss of biodiversity, bare soil, non-target damage to wildlife, eutrophication of waterways etc).

An ecosystem is defined as a biological community of interacting organisms and their physical environment interacting together as a functional unit. Each species has a valuable role to play in the functioning of the system even if it is not immediately apparent.

Healthy ecosystems provide valuable ecological services to humans (Pimentel et al., 1992). These ecosystem services can provide tangible benefits to the vineyard and be enhanced via the adoption of environmental stewardship practices. The objective is to ensure optimal production, fruit quality, and profitability while reducing the need for intervention in the vineyard. Better plant and soil health promotes a more resilient ecosystem.

Biodiversity is typically measured as 'richness' (the number of unique life forms), abundance (number of each life form), 'evenness' (the consistency among life forms), and 'heterogeneity' (the dissimilarity among life forms) (Cardinale et al., 2012).

We believe that each species has value and a right to exist, regardless of its direct benefit to humans, and that we have an ethical responsibility to support this inherent right. Ultimately, our individual, social, and economic wellbeing are all underpinned by being surrounded by healthy and functional biodiversity.

A measure of functional biodiversity is often used to refer to the variety and number of species that fulfil different functional roles (Colwell, 2009), including ecosystem dynamics, stability, productivity, nutrient balance, and other aspects of ecosystem functioning.

For example, a measure of the richness (diversity) and abundance (number) of insect predators can be used when collecting data from different plant communities and individual plant species to represent an objective measure of functionality.

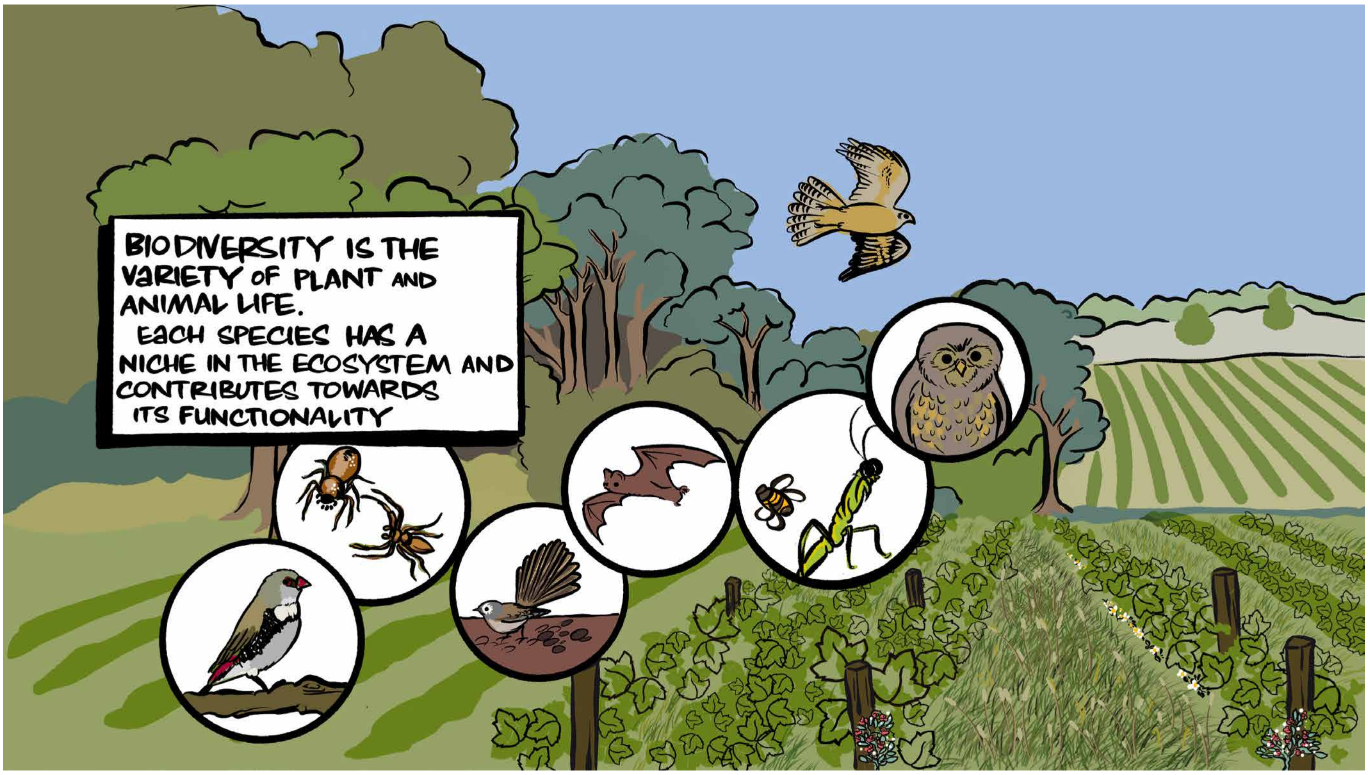


Figure 2. An example of the biodiversity that can be found in an ecologically managed vineyard including predatory arthropods, insectivorous birds, microbats and raptor birds of prey.

One of the challenges with managing a simplistic ecological network with fewer connections like a vineyard monoculture is that it will invariably lead to instability within a production system, and it will require constant human intervention to maintain its function.

Conversely, 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 and rebound after disruption.

As a result, there has been a shift away from managing vineyards where there is a sole focus on crop production to a more integrated and ecologically sensitive approach that not only supports crop production but the entire production system for improved benefits and profitability.

There has been increasing interest in growing wine grapes as efficiently as possible while ensuring they are grown in harmony with nature. This is, in part, because production systems are entirely dependent on the natural resources available, and growers are increasingly called upon to demonstrate their environmental stewardship credentials to customers.

In this guide we discuss the importance of biodiversity and how this relates to functional ecosystem services and the importance of building resilience and stability into production landscapes.

These insights will assist growers to identify ways they can enhance biodiversity, support the role of ecosystem services, intervene less, enhance vine health, fruit quality, profitability, and create longer-term benefits.

THE BIODIVERSITY CRISIS

Dwindling population and range shrinkages amount to a massive anthropogenic (human induced) erosion of biodiversity and the associated ecosystem services essential to civilisation. This loss of functional biodiversity underlines the seriousness for humanity of earth's ongoing sixth mass extinction event (Ceballos et al., 2017).

Unlike previous extinction events caused by natural phenomena, the sixth mass extinction is driven by human activity, primarily the unsustainable use of land, water, energy, climate change and extreme weather events.

The IUCN Red List of Threatened Species is the global standard for assessing the risk of extinction for individual species of animals, fungi, and plants and the Australian Threatened Species Index provides current insights and trends for mammals and birds in each state and territory.

Australia continues to have the most mammal extinctions in the world.

The WWF (2022) Living Planet report tells a disturbing story of continual decline of more than 1,100 wildlife populations in Australia due to pressures from climate change, habitat destruction, and introduced predators.

However, several studies show that the continued loss of wildlife around the world can be prevented. A new metric, known as the International Union for Conservation (IUCN) green status, is helping scientists plot a path to recovery for threatened animals and plants for their potential range and abundance.

This is one of the many reasons that ecological restoration in and around production systems using locally adapted, native plants is important to provide habitat for native fauna that has evolved with and is found in association.

For broader context, the:

- UN Decade on Ecosystem Restoration calls for efforts to prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean.
- Kunming-Montreal Global Biodiversity Framework (KM GBF) calls for 30% of degraded land and water areas across the globe to be under effective restoration by 2030.

The Restoration Decade Alliance (RDA) recently issued a report titled A national approach to attaining nature positive restoration in Australia, in response to Australia's most recent State of the Environment Report and to complement the Wentworth Group's Blueprint to Repair Australia's Landscapes and the NRM Regions Call to Heal Australia's Lands Seas an Waterways reports. The Australian Government's Nature Positive Plan for Australia also seeks to responds to the need for improving our nation's balance sheet in favour of gains for nature rather than losses.

Earth overshoot day

Another initiative to highlight the overuse of resources each year is Earth Overshoot Day, which marks the date when humanity's demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year. For example, if the earth lived like Australia, it would run out of resources by April each year.

This reflects the ecological footprint of a country by comparing the population's demand and the nation's biocapacity.

From April each year onwards, Australia is living on credit at the expense of future generations. If the world's population had the same lifestyle as Australian citizens, the resources of three planets would be necessary to ensure its existence.

NATURAL CLIMATE SOLUTIONS

United Nations decade on ecosystem restoration

There is much focus on the role of natural climate solutions and ecological restoration (Carrington, 2019; Monbiot, 2019; Schwab and Rechberger, 2019) and ways we can avert climate breakdown by restoring ecosystems.

The United Nations Decade on Ecosystem Restoration runs from 2021 to 2030. Its purpose is to promote the United Nation's environmental goals, specifically, to facilitate global cooperation for the restoration of degraded and destroyed ecosystems.

This follows on from the 2011 to 2020 United Nations Decade on Biodiversity. Despite an increase in policies and actions to support biodiversity, indicators show that the drivers of biodiversity loss have worsened, and biodiversity further declined during this period.

The UN defines ecosystem restoration as 'the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity' (United Nations Environment Programme, 2021).

In practice, a particular restoration can involve different transitions, depending on what best suits the local conditions. For example, the UN suggests that a degraded modified ecosystem (e.g. farmland) might be restored to a more functional modified ecosystem by restoring habitat, including hedgerows that can provide habitat for fauna and help improve soil quality.

2011-2020 United Nations Decade on Biodiversity

UNITED NATIONS DECADE ON ECOSYSTEM RESTORATION 2021-2030

Figure 3. The UN initiatives on biodiversity and ecosystem restoration.

United Nations Sustainable Development Goals

In 2015, Australia was one of the 193 countries that adopted the 2030 Sustainable Development Goals. In November 2020, the 'Transforming Australia: SDG Progress Report' stated that Australia was falling behind in the reduction of CO2 emissions (SDG 13), waste and environmental degradation (SDG 12, SDG 14, and SDG 15) and is facing a multitude of complex and integrated crises with climate change and biodiversity decline singled out (Thwaites et al., 2020). The SDG that at its core relates to ecological restoration and functional biodiversity is SDG 15: Life on land.

SDG 15: Life on land: Its goal is to protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and stop biodiversity loss.

Figure 4. The United Nations environmental goals [CC BY-ND 3.0].

Figure 5. The EcoVineyards focus areas of soil health, ground cover, and functional biodiversity contribute to multiple sustainable development goals (SDGs) [CC BY-ND 3.0].

Biodiversity hot spots

Researchers have identified 36 biodiversity hotspots around the world. These are areas that are rich in life but threatened by human behaviour and require urgent protection. They include south-western Western Australia.

The South West Australia Ecoregion (SWAE), Australia's only global biodiversity hotspot, is home to a variety of unique flora and fauna that are under serious threat. This region has the highest concentration of rare and endangered species in Australia.

While the area in and around the Margaret River wine region has 46% remnant vegetation cover, many wine regions will have less than 10% remaining cover, and much of the remnant vegetation present on private land are small parcels that are vulnerable to disturbance and are often degraded because of grazing, weeds, fire, phytophthora dieback, and other disturbances.

We are also seeing dedicated efforts in many wine regions to remove woody weeds and regenerate understorey by planting a diversity of native ground covers and shrubs such as Biodiversity McLaren Vale and Hills Biodiversity in South Australia, Hunter Valley Landcare Network in New South Wales, Nature Conservation and Lower Blackwood LCDC in Western Australia along with many other initiatives in wine regions across Australia.

Environmental, social and governance (ESG)

Some of the biggest emerging trade and market access challenges are because of increased scrutiny of environmental, social and governance (ESG) credentials by regulators, banks, insurers, investors, and, subsequently, the major retailers and distributors. Global wine consumers are also developing a preference for wine that has a focus on environmental stewardship practices. Wine Australia has developed an ESG investment plan to help implement these changes in the wine sector.

Ecological solutions

We focus on providing ecological solutions as this is closely aligned with our desire to grow in harmony with nature and is not prescriptive so there are no perceived barriers to its use and uptake by growers.

Our measure of ecological and environmental stewardship is whether vineyard practices are in harmony with nature. A grower can track their progress by determining if a suite of practices brings them closer or further away from this goal.

Ecologically driven and bottom-up processes seek to transform agricultural production systems by addressing the root causes of problems in an integrated way to provide holistic and long-term solutions.

Sustainable

This is the only time you will read the word sustainable in these guides (unless it is related to a direct quote or reference). There are many ways to describe practices that are focused on environmental stewardship with terms like organic, regenerative, minimal input, and sustainable often used. We don't use the word sustainable as to 'sustain', in our view, is a low bar. We cannot continue to do more of the same and expect a different outcome.

We focus on providing practical solutions for wine growers and are wary of initiatives that may be conveyed as 'tick box' or 'greenwashing'. We wish to accelerate meaningful practice change and information sharing amongst wine grape growers in real time. We urge leadership in the way the wine community refers to environmental stewardship and encourage a focus on regenerative and ecological outcomes.

We are conscious of the urgent need to future proof production and grow resilience in our production landscapes, while focusing on fruit quality, financial security, and environmental stewardship.

Australian sustainability reporting standards

The passage of the Australian Sustainability Reporting Standards through the Senate marks a pivotal moment in how corporations engage with the realities of climate change. From January 2025, companies and asset owners meeting specific financial thresholds will be required to disclose:

- Climate risks and opportunities
- Climate resilience and adaptivity assessments
- Scope 1, 2 and 3 emissions

Each year the financial threshold for reporting and disclosure of the above topics, will be lowered to capture more and more Australian businesses. What does this mean for the longer-term? The quantification and incorporation of metrics, traditionally viewed as non-financial, into business financial and risk analysis. The legislation also provides a standardised method to compare the exposure of various businesses to climate risk, their adaptive capacity and an individual business' decarbonisation plans and progress.

Freshcare Australia

Freshcare Australian Wine Industry Standard of Sustainable Practice – Viticulture and Freshcare Australian Wine Industry Standard of Sustainable Practice – Winery provides the requirements for wine growers and wineries to achieve certification, enabling them to become certified members of Sustainable Winegrowing Australia.

WHY IS THE FUNCTIONALITY OF A PRODUCTION SYSTEM IMPORTANT?

Landscape simplification

When diverse natural systems are replaced with monocultures, this will invariably have a negative impact on biodiversity and species richness (Hooper et al., 2005; Meehan et al., 2011). A simplistic ecological network with fewer connections and low functional biodiversity may lead to instability within a production system (Altieri, 1999; Gurr et al., 2004).

Where there is fragmentation of the landscape, there is often an increase in pest pressure on crops and a greater reliance on chemical control options (Meehan et al., 2011; Orre-Gordon et al., 2013). This is not surprising if the system is poorly buffered and out of balance.

Fragmented landscapes can also have a negative effect on the abundance and diversity of predators (Steffan-Dewenter, 2003) and reduce their capacity to provide biological pest control (Kruess and Tscharntke, 1994).

For example, in France, a reduction in semi-natural habitat has been linked to a reduction of biological pest control in cultivated land (including vineyards) by up to 46% compared with more complex landscapes (Rusch et al., 2016). The effects of habitat loss and fragmentation on herbivores and predators are contingent on the species and landscape (Tscharntke and Brandl, 2004).

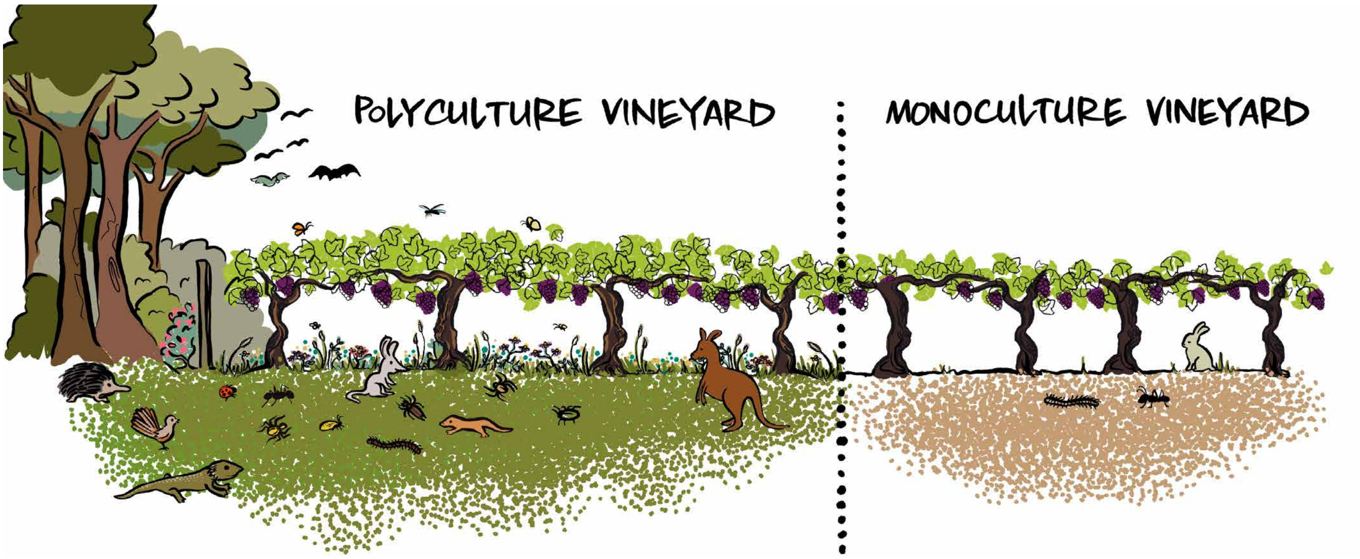


Figure 6. Polyculture versus monoculture vineyard system.

Increasing intensification may become a self-defeating circle where the risk of failure is high. Growers may find that more and more intervention and artificial inputs are required to keep a vineyard productive over the long term.

It is also reported in agricultural landscapes that insecticide use often increases with an increase in the size of a production area and decreases with the proportion of semi-natural habitat present (Meehan et al., 2011).

Biodiversity loss

Loss of habitat is regarded as the greatest threat to biodiversity (Brooks et al., 2002).

- **It is generally regarded that as the proportion of suitable habitat in the landscape is reduced to less than 30% of original vegetation cover, this will cause a loss of biodiversity, that is, a reduction in species numbers and population densities for all fauna (Andren, 1994; Hanski, 2011).**
- **Conversely, in structurally complex landscapes predation and parasitism tends to be higher and crop damage lower than in simple landscapes (Marino and Landis, 1996; Thies and Tscharntke, 1999; Tscharntke et al., 2002).**

A number of consensus statements are proposed in the literature that help to sum up the significance of biodiversity loss and its potential impact on humanity (Cardinale et al., 2012):

- There is indisputable evidence that the efficiency of multiple ecosystem functions is reduced as biodiversity is lost.
- Initial losses of biodiversity in complex ecosystems have relatively low impacts on the functioning of ecosystems, but both the rate of change within an ecosystem and its reduced capacity to function accelerate as biodiversity loss increases (Cardinale et al., 2006).
- Loss of diversity across trophic levels (feeding positions in a food chain) has the potential to influence ecosystem processes more strongly than diversity loss within trophic levels (Duffy et al., 2007; Estes et al., 2011).
- A reduction in the diversity of functional characteristics of organisms will have large impacts on the extent of ecosystem functions (Laureto et al., 2015; Petchey and Gaston, 2006).
- Conversely, there is growing evidence that as biodiversity increases, so does the stability of ecosystem functions through time (Cottingham et al., 2001; Jiang and Pu, 2009).
- Diverse communities tend to be more productive as they contain a variety of species with different functional traits that can increase productivity by producing greater biomass (Cardinale et al., 2012).

It is reported that agriculture is the largest contributor to biodiversity loss with expanding impacts due to changing consumption patterns and growing populations (Dudley and Alexander, 2017).

This statement was further reinforced by Professor Dr Hans Schultz at the OIV conference in 2019 where he stated, "*The food system is the primary cause of biodiversity loss.*"

ENHANCING RESILIENCE AND STABILITY

The resilience of a system describes its capacity to reorganise after local disturbance (Tscharntke et al., 2005) or in response to environmental changes (Oliver et al., 2015).

It is generally accepted that if greater diversity is present, it is less likely that individual weed or pest species will dominate, and a farming system will better able to recover from disruptions, including extreme weather events (Yachi and Loreau, 1999).

By adopting optimised management practices and promoting the richness of the natural enemies present, the density of a widespread group of herbivorous pests can be reduced and this may lead to increased yield (Cardinale et al., 2003).

It has also been recognised by scientists and ecologists that when native vegetation is reduced, natural processes start to break down and fauna species may be lost.

By retaining remnant vegetation and undertaking restoration with native species, this will help support critical natural processes. The idea of corridors to link ecologically rich areas between production areas and on the regional scale is also critically important. For example, small patches of native vegetation. such as remnants or roadside vegetation. may provide important refuges for a range of species and act as stepping-stones to larger inter-connected patches.

With an understanding of the importance of a healthy ecosystem, it is possible to enhance biodiversity in production landscapes and develop more complex networks with greater connections.

Regenerative land and water stewardship along with ecologically compatible vineyard management practices can be employed to ensure vineyards coexist in the landscape and contribute to the enhancement of biodiversity.

Figure 7. A bare earth policy, results in a simplistic network with fewer connections (left) compared to a more complex network or interconnected vineyard system (right) [Photos: Mary Retallack].

Like all complex systems, ecosystems can appear to be working well until a point when they suddenly collapse. The role of biodiversity in maintaining essential services in human modified landscapes is often poorly understood. Ecologically managed and farmed systems are mutually compatible and provide better net benefits for both the environment and production systems.

What can wine growers do to enhance biodiversity?

The agricultural sector plays a primary role in managing large sections of privately held land. Proactive decisions on land use and management have the capacity to positively impact on biodiversity and ecosystem services.

For example, stands of native vegetation adjacent to vineyards have been associated with increased biodiversity (Gagic et al., 2018; Smith et al., 2015; Thomson and Hoffmann, 2010b; Thomson and Penfold, 2012) and provide season-long benefits to boost the activity of predators and parasitoids (Thomson and Hoffmann, 2013). Existing stands of vegetation can be enhanced, new insectary resources can be introduced (Nicholls et al., 2001; Thomson and Hoffmann, 2009b; Thomson and Hoffmann, 2010a) and stands of remnant vegetation can be preserved.

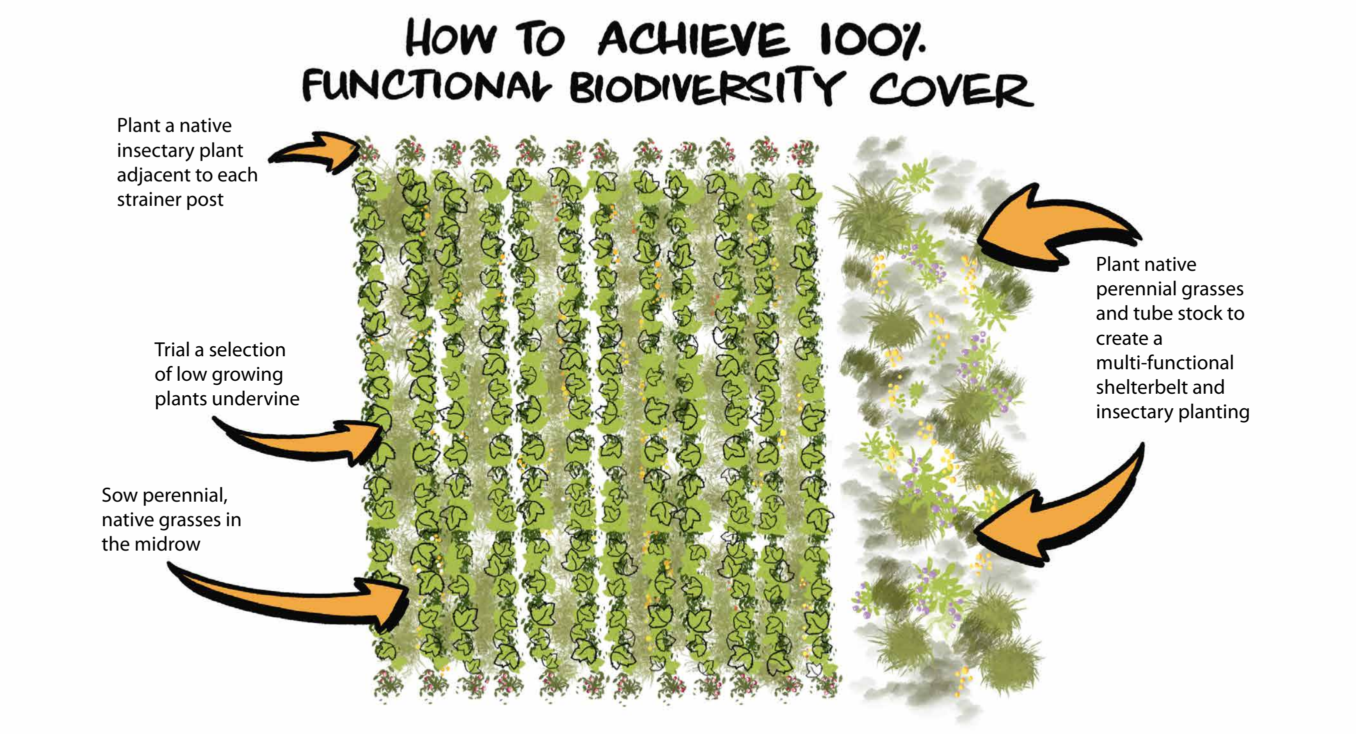


Figure 8. 100% functional biodiversity coverage is possible in vineyards and many perennial production systems.

Vineyards may have a greater potential to retain or reintroduce functional biodiversity than broadacre farming because the land area that is planted with vines is often only an average of 30% of the total vineyard area.

There is no reason why 100% functional biodiversity cover cannot be achieved when you consider the use of ground covers in the mid-row and under-vine areas along with woody prostrate growing ground covers, shrubs, and trees in and around the property.

Habitat management involving the manipulation of vegetation in production systems can exert direct suppressive effects on pests and promote predatory arthropods (Gurr et al., 2017). It is not considered that corridors or revegetation can compensate for the overall loss of habitat provided by original plant cover (Harrison and Bruna, 1999). However, it is possible to implement restorative ecological practices that contribute to bridging this gap by restoring indigenous plant communities (Altieri, 1999).

Stands of native vegetation adjacent to perennial production areas, including vineyards, have been associated with increased biodiversity benefits (Thomson and Hoffmann, 2010b).

Wine growers are encouraged to retain and manage stands of remnant vegetation, protecting them from excessive grazing pressure and noxious weeds and revegetating with native species.

Ecological Infrastructures

Vegetation structures such as windbreaks, vegetation corridors, mid-row or under-vine ground cover and headland plantings can be enhanced or introduced to provide resources for predators that contribute to pest control throughout the year.

Ecological infrastructures are defined as any infrastructure within a radius of 150 metres of a farm or vineyard that has an ecological value to the production system and increases the functional biodiversity of the property, such as hedges, grassland, wildflower strips, conservation headlands, stone heaps etc. (Boller et al., 2004).

There are three important aspects of ecological infrastructures, and they include:

- Large permanent habitats as a basic unit that provide animal populations with permanent habitats.
- 'Stepping stones' or habitats of smaller size allow the build-up of temporary animal populations.
- Corridor structures to assist animal species in moving between large habitats and the small stepping stones (Boller et al., 2004).

The optimum surface of ecological infrastructures (including all structures of interest) to maintain an adequate diversity of species is estimated to be close to 15%.

According to the International Organization for Biological and Integrated Control (IOBC), a minimum of 5% of farmland is required to be designated as ecological infrastructures (Boller et al., 2004).

There is current interest in biodiversity loss due to crop production and the consequent alteration in ecosystem services provision. The presence of non-crop vegetation, including native insectary plants (Schellhorn et al., 2015), may be an important contributor to functional diversity and ecosystem services (Close et al., 2009; Mace et al., 2012).

It is widely regarded that biodiversity is the engine room of ecosystem services.

THE ROLE OF ECOSYSTEM SERVICES

Historically, humans have modified natural ecosystems to exploit species that yield direct benefits, often overlooking the unseen but essential ecosystem services that, if lost, are expensive and sometimes impossible to replace (Close et al., 2009).

Ecosystem services are the suite of benefits provided to humans through the transformation of resources into a flow of essential goods and services in an ecosystem.

The organisms within a system perform a myriad of valuable ecological services. In production landscapes this may include tasks that benefit vineyards, for example, by providing a source of predators for pest control, buffering weather conditions such as extremes in wind and temperature, supporting the recycling of nutrients, regulating hydrological processes including aquifer recharge, minimising soil erosion, and detoxifying chemicals that may otherwise build up within a system (Altieri, 1999; Viers et al., 2013). Enhanced biodiversity is often promoted as an important indicator of vineyard health (Altieri, 1999; Barnes et al., 2010; Gurr et al., 2003; Winter et al., 2018) and non-crop plants may have the capacity to maintain and enhance biodiversity (van Emden, 1965).

If these natural processes are lost the economic and environmental costs may be significant (Meehan et al., 2011).

Figure 9. Ecosystem services that benefit production systems, including vineyards [Image: NatureScot].

Provisioning, regulating, cultural, and supporting services

Ecosystem services are often classified into four categories: provisioning, regulating, cultural, and supporting services (Close et al., 2009; Mace et al., 2012; Schellhorn et al., 2015).

- Provisioning services are the goods or products obtained from ecosystems, such as food, fresh water, timber and fibre or, in the case of grapevines, the grapes that are made into wine. Products of ecosystem services are referred to as 'ecosystem goods'.
- Provisioning services may also relate to insectary plants that can provide services and goods, such as food, shelter, and alternative prey to support the presence of predators.
- Regulating services are the benefits obtained from the control of natural processes such as waste decomposition and detoxification, purification of water and air, and biological control of key pests and diseases.

A key principle of biological control incorporates the use of native insectary plants. By boosting the presence of predatory arthropods, they can provide biological pest control or regulate ecosystem services in vineyards virtually for free once they are established.

Native insectary plants have the capacity to provide 'provisioning' resources, such as food (pollen and nectar), shelter, and alternative prey/hosts (Barnes et al., 2010; Gurr et al., 2017) that nourish predators and extend their presence in a vineyard (Gurr et al., 1998).

In turn, predators provide 'regulating' ecosystem services that contribute to biological control of insect pests. Ecological services also include weed suppression, erosion control, aesthetics, nutrient cycling, soil water retention, soil organic carbon, and soil biological activity (Fiedler et al., 2008; Gurr et al., 2003; Nicholls and Altieri, 2003), which maintain conditions for life on earth and contribute to human wellbeing.

- **Cultural services** include non-material benefits, such as recreation and aesthetic enjoyment. An increasing awareness of the knowledge and connection to land of First Nations people is also being embraced and acknowledged.
- **Supporting services** include natural processes such as nutrient cycling, soil formation, and crop pollination.

Microbial populations are essential for converting many nutrients into plant-available forms and they develop symbiotic relationships with plants, including grapevines, to help improve plant health and resilience against insect attack and plant pathogens.

Conservation biological control (CBC)

Conservation biological control is defined as the conservation and augmentation of predatory arthropods that are already in place or are readily available (Barbosa, 1998).

CBC involves the implementation of practices that protect and enhance the reproduction, survival, and efficacy of natural enemies of pests (Barbosa, 1998; Begg et al., 2017; DeBach, 1974; Fiedler et al., 2008; van Emden, 2003).

This approach could provide innovative, practical, and environmentally friendly solutions for local wine grape growers. If wine growers' plant native insectary plants it is likely they will benefit from the predatory arthropods that have co-evolved with each species and are found in association.

More than 90% of Australia's species of flora and fauna are endemic. Many predatory arthropods are also endemic, have co-evolved with native plants and are likely to be found in association.

Biocontrol

Enhanced functional biodiversity can lead to greater natural biological control, resilience within the system, and improved ecosystem services (Altieri, 1991; Andow, 1991; Stamps and Linit, 1997). By adopting optimised management practices and promoting the richness of the natural enemies present, they could reduce the density of herbivorous pests and this may lead to increased yield (Cardinale et al., 2003).

Biological control is a key component of arthropod-mediated ecosystem services (AMES), which is used to manage pests in production systems (Isaacs et al., 2009).

Biocontrol is estimated to provide five to ten times more control of pests than pesticides (Pimentel et al., 1992).

The success of biocontrol is often dependent on the colonisation of vineyards by predatory arthropods each season due to a resource 'bottleneck' (constrained habitat and food) that may occur over winter when vines are dormant and resources are limited (Schellhorn et al., 2015). One way to overcome a resource bottleneck is through ecological engineering with a diversity of native species including evergreens (Gurr et al., 2004) that have the capacity to provide habitat and floral resources all year.

For example, parasitic wasps from the super-families of Chalcidoidea, Ichneumonoidea, Proctotrupoidea, and Tiphioidea seek out a range of host plants found adjacent to vineyards during the overwintering period and can be found on various native insectary plants, including *Bursaria spinosa*, sweet bursaria, and *Leptospermum continentale*, prickly tea-tree (Retallack, 2019); ladybird beetles also prefer to overwinter at ground level insulated in plant material (Nedved, 1993).

Perennial cover crops have the capacity to activate and influence key processes and components of the agroecosystem (Altieri, 1999). The benefits of preserving native vegetation near horticultural areas include conservation biological control (CBC) and biodiversity enhancement (Bianchi et al., 2006; Fiedler et al., 2008; Frank et al., 2008; Gurr et al., 2003).

For more information on biocontrol of insect pests please refer to the **EcoVineyards fact sheet: Biocontrol of common grapevine insect pests**.

Biodiversity as an indicator of vineyard health

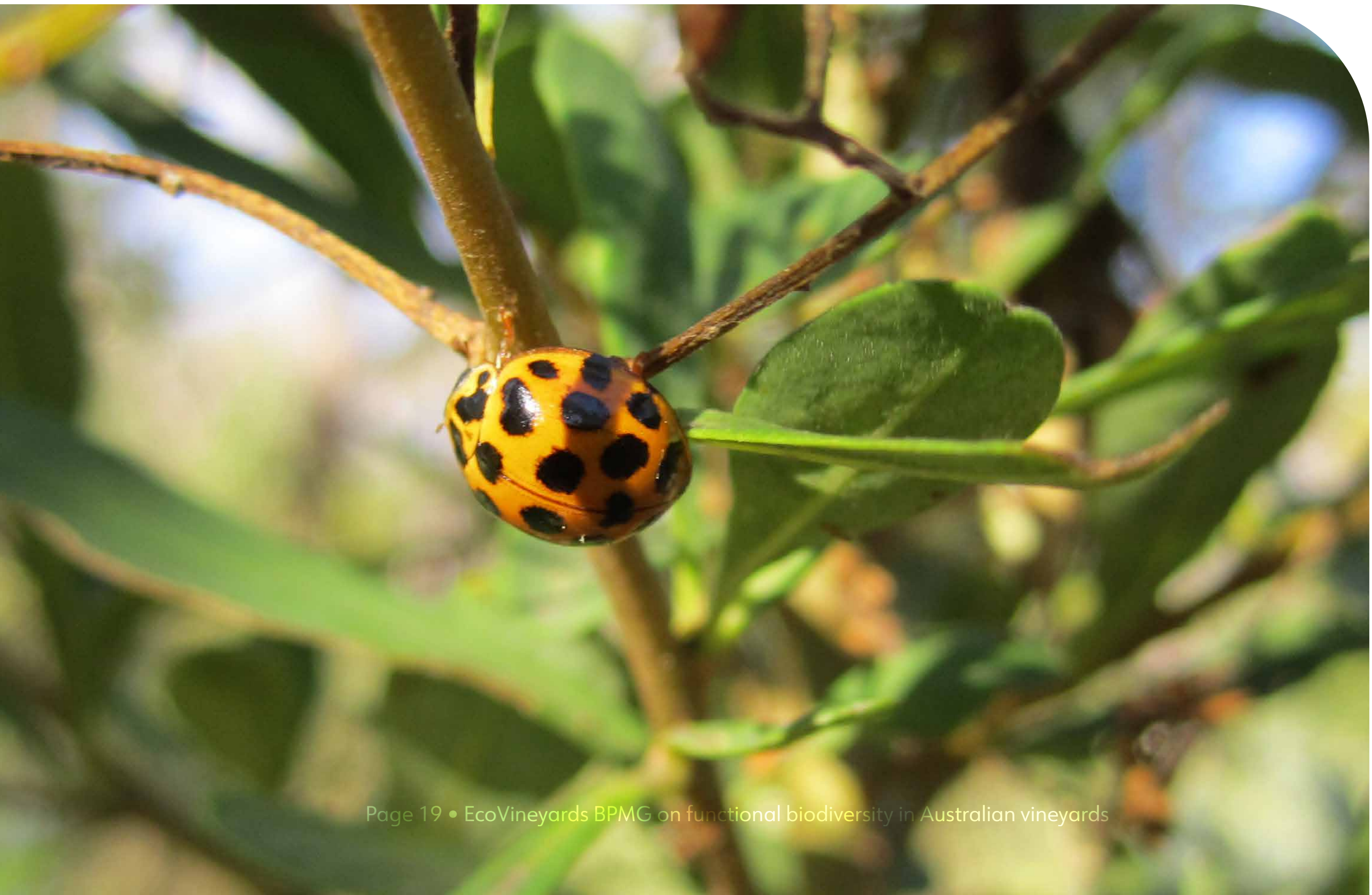
Increased biodiversity is often promoted as an important indicator of vineyard health (Altieri, 1999; Barnes et al., 2010; Bruggisser et al., 2010; Gurr et al., 2003; Thomson and Penfold, 2012; Winter et al., 2018). However, the measurement of biodiversity is difficult. Thomson et al. (2007) suggest that a surrogate indicator such as the diversity of predatory invertebrates, which has a direct impact on pest abundance, can be used as one way to assess the benefits of enhancing biodiversity.

Dr Linda Thomson, The University of Melbourne recommends that the time for focusing on monitoring to assess the benefits of arthropods found in association to justify the benefits of insectary plants is past, in view of the large amount of research clearly demonstrating this benefit (Thomson pers comm, 2024).

As growers consider moving towards an integrated system, it is important to incorporate a diversity of different plant forms. Consider the timing of flowering, a range of different vegetation heights, annual and perennial species, and/or multi-species mix where possible.

KEY MESSAGES

1. **Greater biodiversity is associated with greater resilience and stability in production landscapes. This potentially means that growers can intervene less, saving time and money.**
2. **Monoculture plantings have a negative impact on biodiversity.**
3. **When native vegetation is reduced, natural processes can break down and fauna species may be lost.**
4. **Diverse plantings can provide tangible benefits. Growers can enhance biodiversity through ecological engineering with native insectary plants to enhance the performance of their agroecosystems.**
5. **Improved biodiversity metrics can be captured via environmental reporting programs.**



SECTION 2:

EARLY SUCCESSION, COLONISER OR PIONEER (WEEDY) SPECIES

RECLAIMING BARE SOIL

When we consider the ecology of a site, one of the first things we notice is the role of early succession coloniser (pioneer) plants, which are often referred to as weedy species especially if there is bare soil.

Ecological succession is the process where an ecological community progressively transforms itself from an unstable system towards stability and resilience.

Where soils are bare and sterile, pioneer species may take the form of lichen and moss or an annual species with a fine and spreading root system, followed by tap-rooted forbs (flowering plants without woody stems) and annual grasses, which are generally found in association with bacterially dominated soils.

Then we may start to see the presence of perennial grasses, shrubs and, in some instances, trees, which eventually culminate in a mature 'climax' woodland or forest and signals a habitat with low disturbance and fungal-dominated soils.

The Soil Food Web recommends a 1: 2 to 3.5 ratio of bacteria to fungi in vineyards. Disturbed soils tend to be bacterially dominant, while a lack of disturbance supports fungal population growth and abundance. Perennial woody crops are better suited to a fungal-dominated environment.

Figure 10. Lichen and moss in a sterile undervine area due to prolonged use of herbicides (left) [Photo: Mary Retallack] and native grasses recruited naturally where herbicide application ceased together with sterile conditions where herbicide application continues (right) [Photo: Dan Falkenberg].

An empty paddock left undisturbed for long enough has the capacity to eventually grow into a fully formed open woodland or forest. Given enough time, nature will fill bare or disturbed ground with pioneer plants that quickly stabilise, build soil health, and prepare the ground for progressively larger plants, until the area is filled with a complex mix of both ground cover and upperstorey species.

These areas have the capacity to support functional biodiversity that provides habitat for a wide range of flora and fauna, and a balanced, natural, system where pests and weeds rarely dominate.

An understanding of plant succession can be used to establish favourable sites, address underlying soil health issues, and potentially break the cycle of intervention. If we learn to read what weedy species are trying to tell us, we can gain insights to the health of the system.

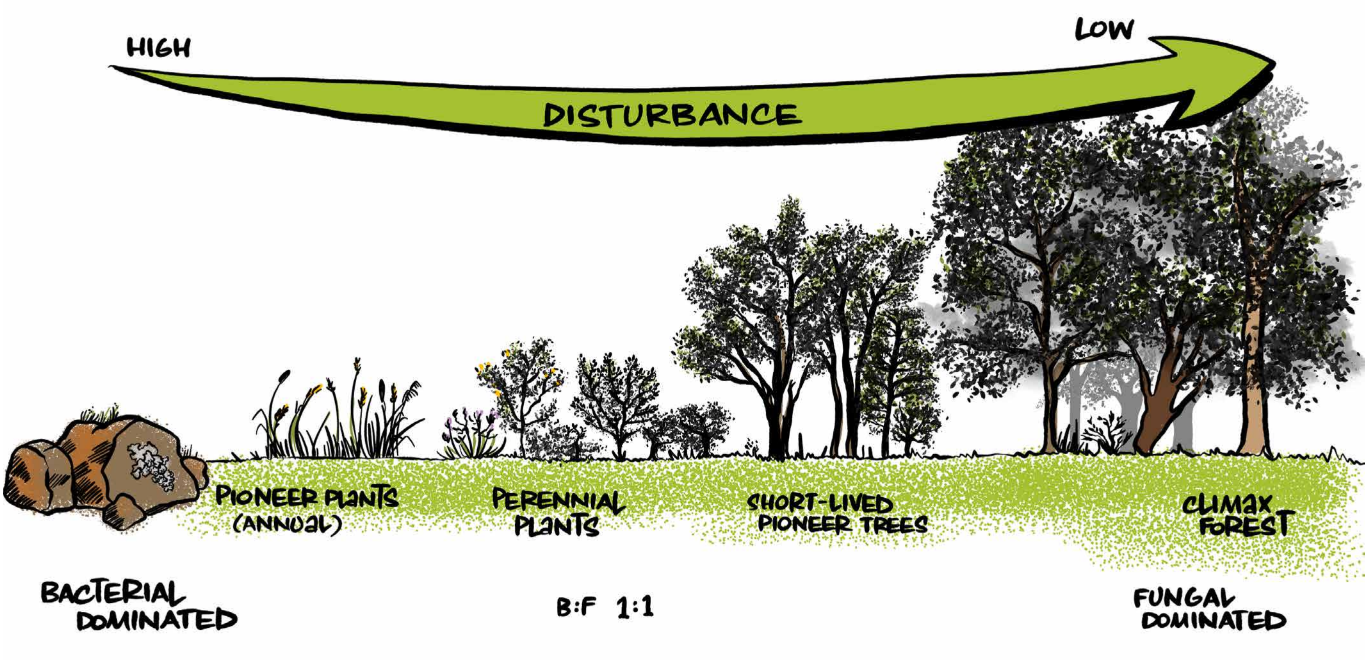


Figure 11. An example of the types of Australian plants involved in ecological succession and the change from bacterial to fungal dominated soils.

The process of ecological succession

- Annual pioneer plants populate disturbed soil, and they often spread by producing many seeds that are dispersed by wind. They are adapted to grow in hot, dry, and exposed conditions, and often in very poor soil conditions. These plants are short lived and improve the soil by creating a layer of mulch, which breaks down to contribute organic matter back into the soil.
- Pioneer plants help to create an environment that can support perennial plants and grasses, many of which have their own special adaptations and survival mechanisms that allow them to further transform what the pioneer plants have left behind.
- Once these changes have taken place, the space becomes suitable for the growth of woody pioneer or shrub species. The transformation into a shrubland elevates the height of the vegetation and creates a protective microclimate that supports the growth of small trees.
- Fast-growing, small, short-lived pioneer trees help to transform the area into a young woodland.
- Short-lived pioneer shrubs and trees are gradually replaced by taller and longer-lived hardwood trees (also called climax trees) with an understorey of shade-tolerant species that grow below them, creating a mature open woodland or forest.

Each time the land is cleared or pioneer plants that are growing to protect bare land are removed, this ecological process starts again in a counterproductive cycle.

Conventional agricultural systems aspire to maintain the ground at annual (weedy) plant stage. It takes an immense amount of energy and time to try and reverse natures processes, while also burning huge amounts of fossil fuel in the process!

Nature will always fill a void, so the ongoing pursuit to create bare ground is futile and in fact one of the most damaging practices to the production system both in the short and long term. Bare earth creates the conditions for desertification.

Learn to read your weeds

Weedy species are an important indicator of soil health and integrity. Weeds can provide valuable insights to underlying soil issues.

Many weeds act as accumulators of minerals in deficient soils and when they die and decay, the minerals are returned to the soil in a form that is plant available. There are many other benefits of having plant cover in preference to bare soil and we wish to provide a broader perspective of the role they play.

Early colonisers include moss, lichen, and ferns (also called cryptogams, or plants that reproduce by spores without flowers or seeds). They help to provide protection of the soil surface when there are no flowering plants present and where soils are sterile due to excessive weedicide application.

Cryptograms provide food for soil arthropods and larger herbivores and often remain dormant in dry conditions until moisture stimulates them to grow and photosynthesise. They help store carbon and provide a source of nitrogen.

The use of herbicides in a vineyard is often problematic with many weedy species quickly becoming herbicide resistant. What might be considered competition from weeds may, in fact, be due to other factors, including allelopathy (i.e., *Polygonum aviculare*, wireweed, and *Lolium* sp., ryegrass), which produce suppressive chemicals, or weedy species that feed bacterially dominant soils via their exudates.tab

Some of the reasons for the prevalence of weedy species include sites with:

- bare or sandy soil (i.e., *Tribulus terrestris*, caltrop; *Portulaca oleracea*, pigweed/purslane). Often these plants have a prostrate growth habit and quickly cover bare ground.
- heavy clay soil (i.e., *Elymus repens*, couch grass; *Plantago lanceolata*, plantain)
- bacterial dominated (i.e., *Arctotheca calendula*, capeweed; *Elymus repens*, couch grass; *Cenchrus clandestinus*, kikuyu grass; Hordeum jubatum, foxtail barley; *Avena fatua*, wild oat)
- fungal dominated (i.e., *Alcea* sp., hollyhock; *Hypericum perforatum*, St John's wort; *Ulex europaeus*, gorse; *Cytisus scoparius*, English broom; *Lycium ferocissimum*, African boxthorn)
- compacted (i.e., *Cichorium intybus*, chicory; *Plantago lanceolata*, plantain; *Rumex crispus*, curled dock; *Taraxacum officinale*, dandelion; sedge and rush species)
- poor draining or waterlogged (i.e., *Rumex* sp., dock; *Malva parviflora*, marshmallow; sedge and rush species)
- low in nutrients (i.e., *Taraxacum officinale*, dandelion; fern species; *Plantago lanceolata*, plantain; *Onopordum acanthium*, Scotch thistle)
- high in nutrients (i.e., *Cichorium intybus*, chicory; *Portulaca oleracea*, pigweed/purslane; and *Chenopodium album*, fat hen)
- high in nitrates (i.e., *Arctotheca calendula*, capeweed; *Urtica dioica*, stinging nettle; *Chenopodium album*, fat hen; *Hordeum jubatum*, foxtail barley; *Sonchus oleraceus*, milk thistle)
- high in available potassium and low in phosphorus (i.e., *Solanum nigrum*, blackberry nightshade; *Taraxacum officinale*, dandelion; *Portulaca oleracea*, pigweed/purslane; *Plantago lanceolata*, plantain; *Onopordum acanthium*, Scotch thistle; *Raphanus raphanistrum*, wild radish; *Hypericum perforatum*, St John's wort)
- low pH (acidic) (i.e., *Rubus* sp., blackberry; *Taraxacum officinale*, dandelion; *Plantago lanceolata,* plantain)
- high pH (alkaline) (i.e., *Chenopodium album*, fat hen; *Polygonum aviculare*, wireweed).

Figure 12. Fat hen can be found on a wide range of soils that are often rich in nitrogen and alkaline [Photos: Sheldon Navie].

Figure 13. Kikuyu is an indicator of very low calcium and phosphorus, high potassium, very high magnesium and iron, low humus, and compacted soils [Photos: Sheldon Navie].

Figure 14. Marshmallow is an indicator of very low calcium and soil organic matter, high potassium, iron, aluminium, and very high magnesium. It is also an indicator of compacted soil [Photos: Forest, Kim Starr, and IEWF].

Most weedy species compete poorly and thrive only in environments that lack competition from other species. This is why managers of bare-ground vineyards are often in a constant struggle against weed colonisation. They are continually resetting the system back to the start of ecological succession. It is a no-win situation that will continue to consume time and resources; nature will always fill the void.

How to accelerate the process of ecological succession

The best solution to overcome weedy areas is to populate the ground with a selection of desirable ground covers that have a range of functional traits that will provide the outcomes needed on a particular site and, in doing so, weedy species are far less likely to dominate.

One of the underpinning principles of functional biodiversity is that when a system is in balance it is unlikely that pest weed or insect species will dominate.

A bacterial-dominant soil will tend to support annual weedy species, whereas a fungal-dominant soil will support perennial and/or woody species.

It is likely that weeds are present because the soil has a deficiency or lacks a condition that allows them to thrive, thus prompting nature to repair systemic damage.

There are several ways to work with the flow of nature and accelerate the benefits of ecological succession. They include:

- **Working with what you have**

Utilise existing annual pioneer plants and weedy species to increase soil health if they are providing functional benefits, stabilising the soil, accumulating minerals, and providing mulch when they die.

Graze or slash annual species before they set seed to interrupt the reproductive cycle. Smother unwanted plants with a thick layer of compost or mulch to suppress further growth. Plant a diverse mix of perennial species to outcompete new growth from annual weedy species. The process of solarisation – covering the soil with clear (not black) UV stable plastic for several months over summer – may provide an effective remedy where there are small patches of unwanted weeds.

Perennial weedy species often regrow if they are slashed and may need to be physically removed or cultivated to get rid of them quickly. However, soil disturbance may trigger the annual weed seeds, which are sitting dormant in the soil, to germinate and re-populate the disturbed area. Conversely, if there is active competition and/or an upperstorey shading ground cover species, then annual species are likely to regress over time.

- **Plant a diversity of native perennial species**

Consider planting naturally adapted, native plants that will survive hot, dry conditions. By covering bare land with nature's solar panels, they will convert light energy via photosynthesis into sugars (glucose) that are exuded by the roots to support populations of microorganisms, including bacteria, fungi, protozoa, and predatory nematodes.

They, in turn, help to nourish plants by increasing soil organic matter, plant-available nutrients, and soil water-holding capacity. They also create suitable conditions for higher-order, woody, ground cover plants and shrubs (including crops like grapevines and orchard trees).

Seek out local pre-European plant community lists to help inform the selection of appropriate plant species. For more information, please refer to the EcoVineyards **native plant lists**.

- **Incorporating organic matter**

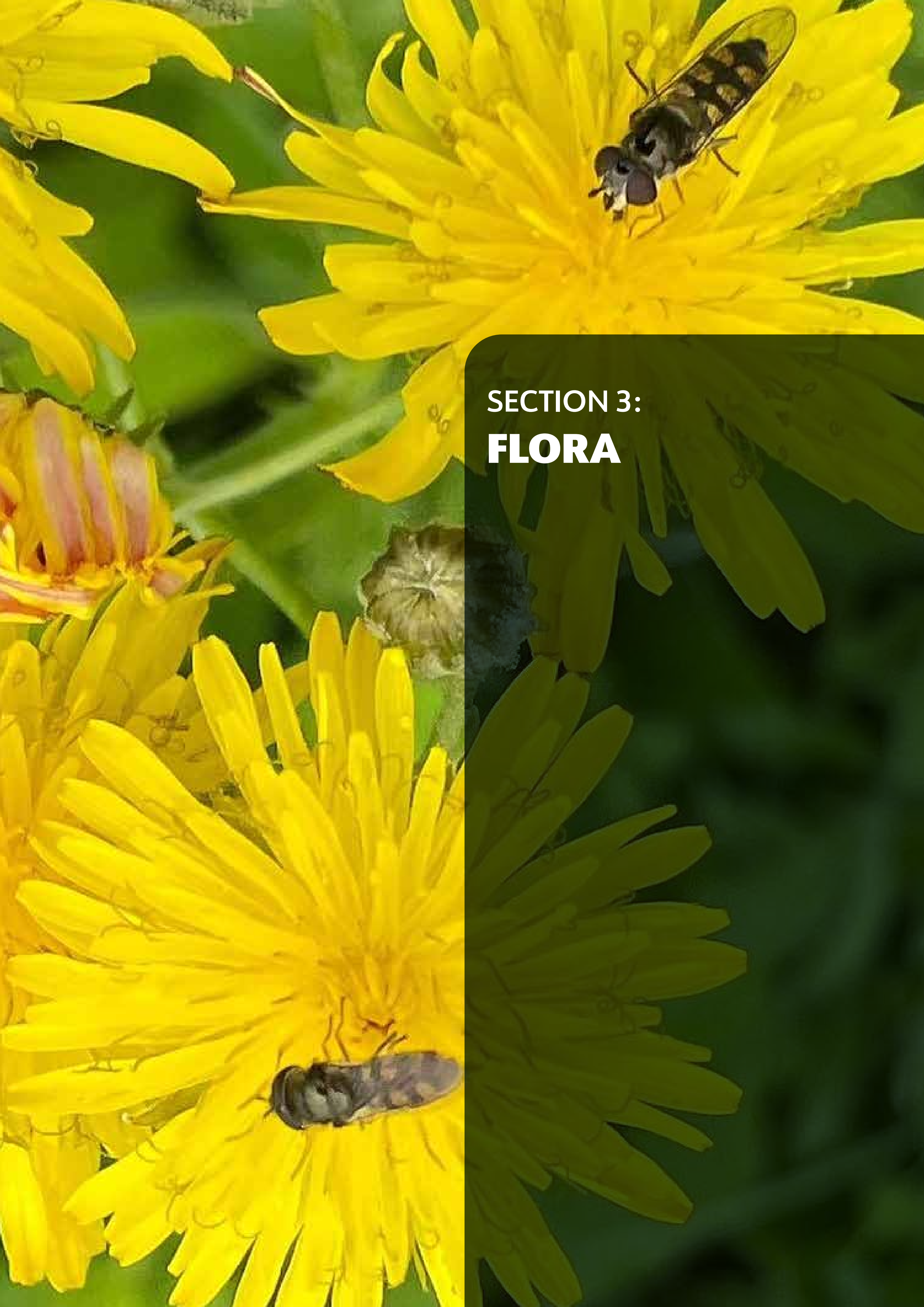
It is possible to improve soil health and resilience by adding organic matter to the soil through the application of mulch, compost, green manures, or natural fertilisers such as manure, seaweed, worm castings, and feed soil microorganisms via the application of high thermal, aerated, fungal-dominant compost tea and/or fish hydrolysate. Ideally, any organic matter that is needed is grown on site rather than trucking it in.

- **Select plants that support ecological succession**

We can choose native species to accelerate ecological succession rather than relying on the natural recruitment that may occur on site, which may comprise a mixture of native and introduced plants. While grapevines may be the focal cash crop, it may also be possible to incorporate additional native bush foods, or to harvest native grass and forb seeds to provide an additional income stream.

Native insectary plants provide habitat (a source of food, shelter, and/or alternative prey) for a range of life forms, including insectivorous and raptor birds, microbats, reptiles, frogs, turtles, and predatory arthropods.

We can work with nature to speed up ecological succession while potentially benefiting from a myriad of ecosystem services.



SECTION 3:

FLORA

INSECTARY PLANTS

The use of non-crop plants or supplementary flora as insectary plants to provide habitat for predatory arthropods was reported as early as the mid 1960s (van Emden, 1965). The presence of insectary resources to nourish predatory arthropods in vineyards provides a way to attract and maintain populations of predators.

Many natural enemies that attack crop pests are native (Gagic et al., 2018) and have co-evolved with native flora. An increase in predator richness and abundance is reported where there is native vegetation adjacent to cropping areas (Landis et al., 2005; Landis et al., 2000; Parry et al., 2015).

SNAP

Arthropod 'provisioning' services are derived from insectary plants that provide 'SNAP', an acronym that refers to shelter, nectar, alternative prey and pollen (Barnes, et al. 2010). Insectary plants have the capacity to nourish predatory arthropods and extend their presence (Gurr, et al. 1998).

In turn, predatory arthropods provide 'regulating' ecosystem services that involve biological suppression of vineyard pests (Altieri et al., 2005; Nicholls et al., 2000; Paull, 2007; Simpson et al., 2011; Thomson and Hoffmann, 2009a; Viggiani, 2003; Williams and Martinson, 2000). Ecosystem services can be enhanced through 'ecological engineering' with native flora (Gurr et al., 2004).

Selected native plants have the potential to deliver high levels of provisioning services that improve the reliability of biological pest control.

If a monoculture of plants is used, they may need to be carefully screened to ensure they do not provide breeding sites for pest arthropod and/or bird species. However, a diversity of locally adapted plants is unlikely to cause problems.

SNAP is an acronym used to describe arthropod 'provisioning' services (Barnes et al., 2010; Gurr et al., 2017):

- **Shelter**
- **Nectar**
- **Alternative prey/hosts**
- **Pollen.**

SNAP provide essential resources required by predators to survive and thrive (Altieri and Nicholls, 2004; Coombes and Sotherton, 1986; Corbett and Plant, 1993; Eubanks and Denno, 1999; Landis et al., 2000; van Emden, 2003).

Shelter, non-host food, including nectar (Gillespie et al., 2016; Heil, 2015; Lavandero et al., 2005; Siekmann et al., 2004; Zemenick et al., 2018), pollen and alternative prey/hosts all contribute to sustaining populations of predators. While floral resource availability is important, the provision of structural refuges, alternative prey and other attractive qualities may be critical to support particular predatory functional groups (Hogg and Daane, 2015). By focusing on select perennial insectary plants it may be possible to configure plantings to support particular beneficial taxa (Gareau et al., 2013).

For example, wallaby grasses provide habitat for a diversity of predators, including wolf spiders (Retallack et al., 2019a), and breeding sites for brown lacewings (Wood et al., 2011). Native evergreen shrubs provide habitat for brown and green lacewings, spiders, predatory and parasitic wasps, ladybird beetles, and predatory shield bugs (Retallack, 2019).

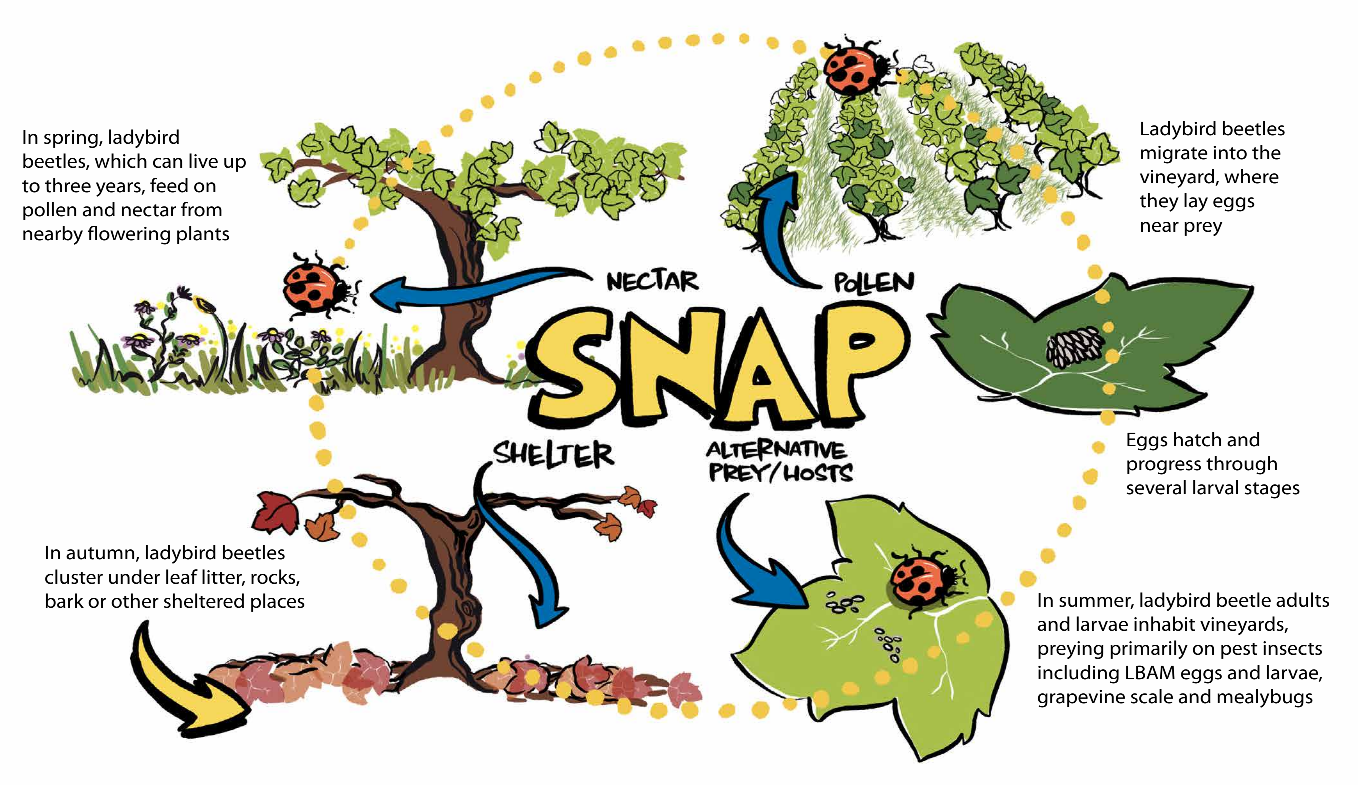


Figure 15. The life cycle of ladybird beetles and the role of SNAP.

Biological control is an example of a regulating service and is also a key component of arthropod-mediated ecosystem services (AMES), which naturally suppress pests in vineyards (Isaacs et al., 2009).

When there is a diversity of predatory arthropods, they target different life stages of economically damaging pests, thereby reinforcing pest suppression (Hogg and Daane, 2014).

Predatory arthropods that attack pests, such as spiders, brown and green lacewings, ladybird and carabid beetles, and predatory bugs are commonly found in vineyards (Bernard et al., 2007; Thomson and Hoffmann, 2009a).

The majority of predators that attack crop pests are native (Gagic et al., 2018) and tend to be found in close association with native plants.

If the numbers of predators are low, biocontrol agents from a commercial insect supplier can be purchased and released. Existing predatory arthropod numbers can then be boosted in the longer-term if suitable insectary resources are present to sustain the populations.

Locally adapted native plants are preferred as supplementary flora as they are naturally adapted to local climatic conditions (Danne et al., 2010; Pandey et al., 2018), and are consistently reported as having a low occurrence of pests (Parry et al., 2015) and a high occurrence of natural enemies (Gagic et al., 2018; Gurr et al., 2017).

Research demonstrates that when compared to introduced species, native plants increase both species richness (the number of species present) as well as species abundance (the total number of a given species present) with plants local to the region performing best (Fenoglio et al., 2023; Mata et al., 2021). Management that encourages indigenous rather than introduced plants not only promotes indigenous biodiversity but also provides less benefit to introduced species (Threlfall et al., 2017). Native perennial ground covers provide food and habitat and be more compatible with crop management than exotic annuals (Daane et al., 2018).

For example, the longevity of parasitoid wasps increases up to 3.4 x when they are exposed to flowering shoots of *Leptospermum* spp. when compared to buckwheat (Pandey et al., 2018).

Introduced insectary species

A small suite of exotic insectary plants, such as *Fagopyrum esculentum*, buckwheat, which is native to Asia, *Lobularia maritima*, alyssum, which is native to the Mediterranean and southern Europe, and *Phacelia tanacetifolia*, phacelia, which is native to California, have come to dominate the literature (Fiedler and Landis, 2007a). They are frequently used outside their natural ranges.

Even though these plants are recognised for their superior provisioning services elsewhere, their performance when used locally has been variable due to Australia's hot and often dry conditions (Thomson and Penfold, 2012). In non-native habitats introduced plants may not prove to be as easy to establish and maintain.

Figure 16. Buckwheat (left) and alyssum in flower (right) [Photos: Mary Retallack].

It has also been reported that the presence and longevity of light brown apple moth (LBAM) may be extended in the presence of buckwheat (Begum et al., 2006) when planted as a monoculture and its fecundity (reproduction capacity) could be enhanced by the availability of nectar plants, such as *Borago officinalis*, borage; *Trifolium repens,* white clover; and *Brassica juncea,* brown mustard (Begum, et al. 2006). Therefore, it appears that the use of some recognised insectary plant species may be counterproductive in some situations.

Introduced insectary plants provide some habitat benefits; native insectary plants are better and native insectary plants from the same location are best in terms of the richness and abundance of predatory arthropods found in association.

‘Random’ versus directed approaches

There are two main ways of incorporating insectary plantings in and around production areas:

- A ‘random’ approach, which involves the planting of a diversity of plant types or seeds mixes with the assumption that ‘diversity is better’ and will be beneficial to pest control (Gurr et al., 2005).
- A targeted and more directed approach is preferred that takes into account optimal forms of diversity (Jervis et al., 2004), floral resources (Berndt and Wratten, 2005; Berndt et al., 2002), and community dynamics within food webs (Polis and Strong, 1996).

Screening and ranking candidate insectary species

Careful screening of candidate insectary plants is required to ensure success. They need to be attractive to predators and be easy to establish and maintain without actively competing with the crop or providing habitat for pests. A range of functional attributes is deemed important and it is suggested that growers focus their efforts on selecting insectary plants that provide multiple benefits (Fiedler et al., 2008). Growers may also consider crops as dual use insectary plants with the potential to provide value added benefits as a cash crop, such as native grass and forb seed production to help generate additional income.

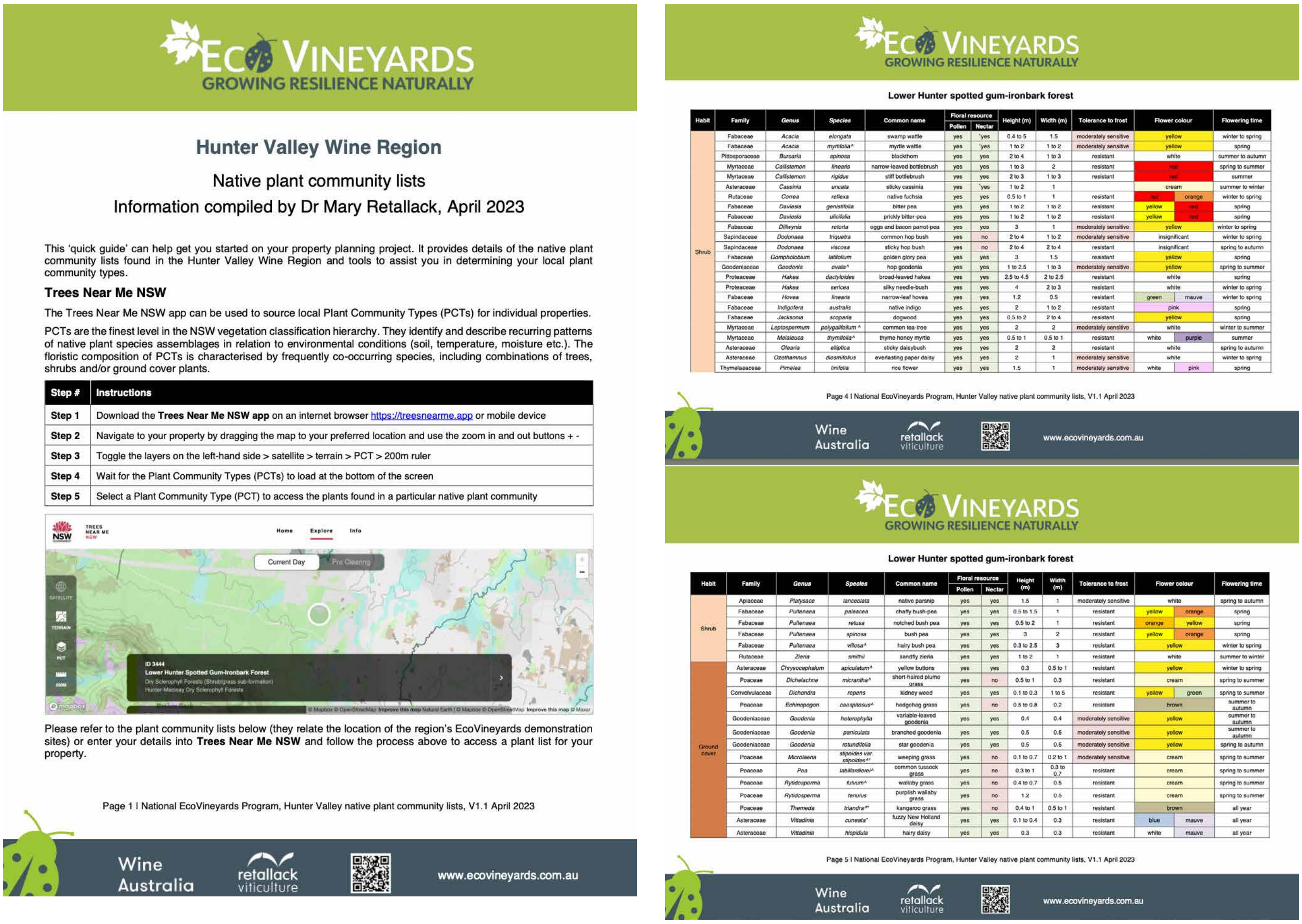
Criteria that were used to guide the process of screening and ranking potential candidate plants (Fiedler and Landis, 2007b; Fiedler et al., 2008; Isaacs et al., 2009; Landis et al., 2000) are presented below:

- Plant species that are native to the local area, naturally adapted and suitable for use in and around vineyards, with little or no inputs (irrigation, fertiliser) required post establishment.
  - Use plants that are commercially available, or seed that is easy to source, collect, and/or strike.
  - Insectary plants that can collectively provide floral services throughout the entire year (including evergreen plants that provide continuity of resources when grapevines are dormant).
- A diversity of different locally adapted native plants, representing different morphologies and heights.
  - An abundance of smaller flowers is preferred otherwise bees may deplete the available resources if only large flowers are present (Conner and Rush, 1996; Hegland and Totland, 2005).
  - Some flowers are ‘buzz pollinated’ and their resources can only be accessed by native bees, or the nectar from long, narrow flowers may only be accessed by species with long mouthparts e.g. butterflies (Baggen et al., 1999; Houston and Ladd, 2002; Jervis, 1998; Wackers et al., 1996).
  - Flower colour may impact the attractiveness to different predators and parasitoids, for example, the parasitoid wasp, Trichogramma carverae, is reported to associate with the white flowers of alyssum to a greater extent than the other colours of the same cultivar (Begum et al., 2004).
  - Flower phenology and synchronicity throughout the year (Long et al., 1998; Rebek et al., 2005; Stephens et al., 1998; Winkler, 2005).
  - Plants that prolifically produce pollen and/or nectar (Zhao et al., 1992).
- Attractiveness to predators (Bugg and Wilson, 1989; Maingay et al., 1991; Patt et al., 1997).
  - The timing of pollen and nectar production coincides with the needs of predators and parasitoids, especially during spring/summer when biocontrol is critical (Colley and Luna, 2000; Jervis et al., 1993; Siekmann et al., 2001).
- Plants that do not provide resources for herbivorous pests (Ambrosino et al., 2006; Baggen and Gurr, 1998; Fiedler and Landis, 2007a).

Native plant species lists

Desktop assumptions should always be tested in the field, and this is the approach used by the national EcoVineyards program. We work closely with EcoGrowers throughout Australia to test the performance of plants in the field via demonstration sites.

Once the performance of an insectary plant is determined on a particular site, the grower then has the confidence to scale up from there either using seeding techniques or by planting tube stock.


ECO VINEYARDS
GROWING RESILIENCE NATURALLY

Hunter Valley Wine Region

Native plant community lists

Information compiled by Dr Mary Retallack, April 2023

This 'quick guide' can help get you started on your property planning project. It provides details of the native plant community lists found in the Hunter Valley Wine Region and tools to assist you in determining your local plant community types.

Trees Near Me NSW

The Trees Near Me NSW app can be used to source local Plant Community Types (PCTs) for individual properties.

PCTs are the finest level in the NSW vegetation classification hierarchy. They identify and describe recurring patterns of native plant species assemblages in relation to environmental conditions (soil, temperature, moisture etc.). The floristic composition of PCTs is characterised by frequently co-occurring species, including combinations of trees, shrubs and/or ground cover plants.

Step #	Instructions
Step 1	Download the **Trees Near Me NSW app** on an internet browser https://treesnearme.app or mobile device
Step 2	Navigate to your property by dragging the map to your preferred location and use the zoom in and out buttons + -
Step 3	Toggle the layers on the left-hand side > satellite > terrain > PCT > 200m ruler
Step 4	Wait for the Plant Community Types (PCTs) to load at the bottom of the screen
Step 5	Select a Plant Community Type (PCT) to access the plants found in a particular native plant community

Please refer to the plant community lists below (they relate the location of the region's EcoVineyards demonstration sites) or enter your details into **Trees Near Me NSW** and follow the process above to access a plant list for your property.

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Lower Hunter spotted gum-ironbark forest

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ECO VINEYARDS
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Lower Hunter spotted gum-ironbark forest

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Figure 17. Plant community lists [Images: Mary Retallack].

The use of native insectary plants is a great way to showcase our unique Australian flora and stand out in a crowded international marketplace. Not only are these plants functional but they look great also!

Native plant community lists have been prepared for participating wine regions around Australia and can be accessed via the EcoVineyards website.

For more information on native grasses please refer to the **EcoVineyards best practice management guide on ground covers**.

Location of insectary plantings

The structure and composition of the adjacent landscape will have an influence on the capacity of the habitat to encourage predatory arthropods into production areas (Colunga-Garcia et al., 1997; Thies et al., 2003). Predatory arthropods will respond differently to the size, location, and diversity of insectary plantings (Banks, 2000; Fraser et al., 2008; Tscharntke et al., 2007; Werling and Gratton, 2008).

The spatial capacity of predators to prey on pest species will be determined by the distance they disperse into the vineyard from insectary plantings and their movement capabilities (Bugg, 1993; Landis, 1994; Lewis, 1965; Pollard, 1968; Roland and Taylor, 1997). Their migration may also depend on visual preferences and plant volatile cues (Suckling et al., 2012). Australian research indicates it may be challenging to encourage certain parasitoid species into the vineyard. Feng et al. (2015) found *Dolichogenidea tasmanica* parasitised the most LBAM larvae in vineyards, while *Therophilus unimaculatus* (Hymenoptera: Braconidae) was most active in adjacent native vegetation.

The spatial area explored by predators during their lifetime may not be sufficient to ensure their movement into the vineyard. 'Islands' of insectary vegetation may be required within production landscapes (Thomas et al., 1991) to facilitate the movement of individuals among the vines. The vineyard floor provides an example of this utility. The mid-row covers more than two thirds of the vineyard area and is suitable for planting native cover crops and facilitating connectivity between patches (Danne et al., 2010; Penfold, 2010; Penfold and McCarthy, 2010; Thomson et al., 2009) with a diversity of grasses, forbs, and low growing woody plants.

Please see the list in **Appendix 1: Suggested uses of native insectary plants**.

Suitability of ground covers in the under-vine area

It may also be possible to plant low-growing insectary plant species that are suited to the under-vine area (Penfold, 2018). These plants should be naturally adapted to a site and have a low requirement for water and ongoing maintenance. Given the slow growing nature of native ground covers, it is unlikley they will compete with grapevines in a vineyard setting.

A team of researchers at the University of Adelaide recently completed a study looking at the use of a low-growing kneed wallaby grass, *Rytidosperma geniculatum*, which grows to 20 cm under vine and found that the dormancy trigger normally present after flowering in early summer is overridden when moisture is available via the dripline.

Growers should be aware that there may be a short-term impact on yield on low vigour sites if weedy species dominate prior to native grasses establishing, but this should come back into equilibrium once the native grasses are established, with multiple functional ecosystem service benefits anticipated in the medium to long term.

For example, in a 2018 study, during the first year that wallaby grasses were planted in the under-vine area there was a 1.6 t/ha decline (-18%) in grapevine yield while they were establishing compared to the control (herbicide strip). In year two there was an increase in grapevine yield by 0.8 t/ha (+9%) and in year three there was an increase of 1.6 t/ha (+26%) compared to the control. This highlights the importance of weed control in year one while native plants are establishing and looking at the benefits over two to three or more years.

Some introduced species, such as phalaris, plantain, paspalum, kikuyu, couch, Yorkshire fog, cocksfoot and fescue, may be unsuitable when planted under vine as they may grow into the grapevine canopy and/or have a detrimental effect on vine vigour due to their vigorous growth habit.

Mobile wicking beds

The use of wicking beds works well if growers would like to prepare a small-scale mobile insectary. This technique has been successfully trialled in Victoria in the vegetable industry and has also been used in vineyards (Karen Thomas, pers comm. 2024).

There are many low-growing insectary species that are suitable for planting in wicking beds as tube stock. Please refer to the suggestions in Table 6.

Figure 18. Mobile wicking bed after planting (left), with plants growing well (right) [Photos: Karen Thomas] and a Warners Nursery insectary container bed (below) [Photo: Warners Nursery]

Suggested placement of insectary plantings

Environmentally friendly farming practices and agroecosystem planning play a crucial role in functional biodiversity enhancement. For example, it is recommended to:

- Plant shrubs adjacent to strainer posts (or set back one metre from strainers to allow for the application and removal of bird netting in summer or electric fencing to keep sheep inside the vineyard perimeter during winter) or at the ends of each row in places where they do not interfere with vineyard practices.
- There should be at least two x 20 metre rows of hedges per hectare. Hedges constitute biological hotspots, acting as corridors linking up ecological areas (Stefanucci et al., 2018).
- The provision of compensatory areas (at least 50 m² per hectare) as diversity hotspots both within and on the perimeter of a vineyard (Stefanucci et al., 2018).
- The success of a CBC strategy is strongly linked to the availability and quality of ecological infrastructures inside and outside the farm within a radius of 100 to 200 metres (Stefanucci et al., 2018).
- Extensive research in southeast Australian vineyards also suggests increases in beneficial arthropods will be seen 100 metres into the vineyard (Thomson and Hoffmann, 2013) where there are adjacent stands of native vegetation.
- In some New Zealand vineyards, the use of flowering buckwheat in one row in ten (every 25 metres) reduces leafroller populations to below economic thresholds (Bernard et al., 2006b).
- The provision of structural elements, such as piles of stones or wood, provide a habitat for reptiles, insects, and small birds. The provision of nesting aids for insects and birds can be integrated into trellis posts. Predator perches can be erected for birds of prey that can deter fruit-eating birds and help keep rodent populations in check.

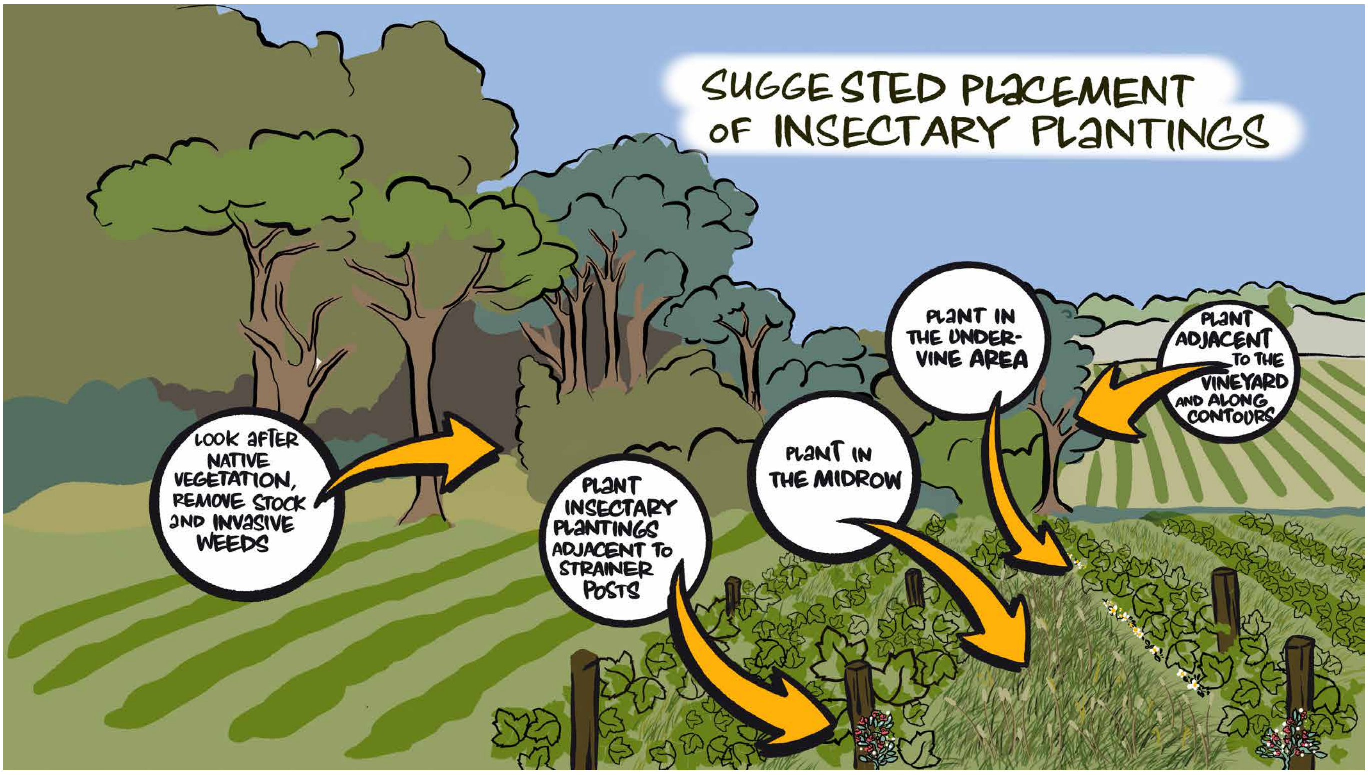


Figure 19. Suggested placement of insectary plantings.

Growers are encouraged to look after remnant stands of native vegetation (remove stock and invasive weeds) and plant insectary plants in the mid-row, under-vine area, adjacent to strainer posts, adjacent to the vineyard (windbreaks) and along contours.

Replacing exotic rose bushes with native species adjacent to strainers

In Australia, rose bushes planted adjacent to strainers provide no intrinsic value and are being replaced with locally adapted insectary shrubs and ground cover plants to improve functional benefits (Retallack, 2018a).

Figure 20. Introduced species, including rose bushes, are increasingly being replaced with native insectary plants [Photo: Mary Retallack].

Ecological infrastructures

Ecological infrastructures include stone walls and raised beetle banks that can provide valuable habitat and connectivity for a range of soil-dwelling arthropods (beetles and spiders) and lizards, especially in spaces where there is sparse flowering vegetation.

Figure 21. Dry stone walls also provide valuable habitat for lizards, small birds, and arthropods [Photo: Mary Retallack].

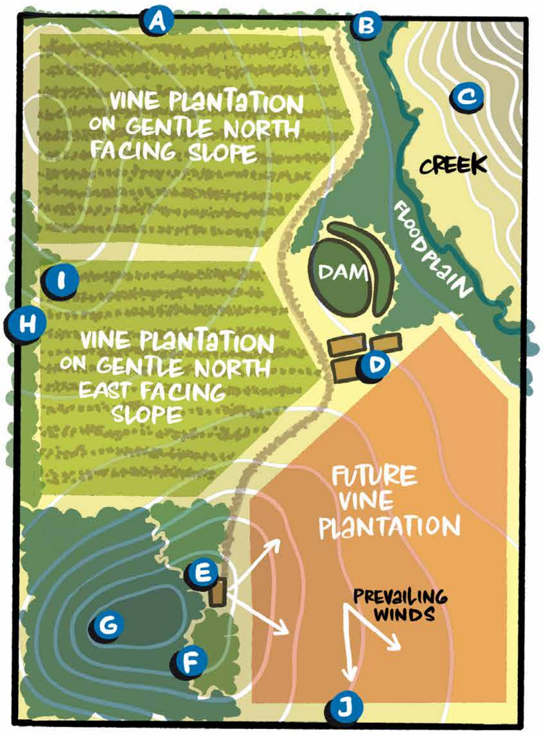
Vineyard planning and layout for insectary plantings

A Planting along road frontage to shelter vines from prevailing winds, enhance the appearance of the property, and to link remnant bushland. Consider native insectary species that can produce food and shelter for beneficials in the vineyard and encourage predatory bird species, which are less likely to eat grapes and will actively deter pest bird species.

B Planting along the creek using indigenous species to provide a buffer to the creek and protect against spray drift, erosion etc. This can help to buffer winds into the vineyard and act as a wildlife corridor.

Remember to plant low ground covers, medium bushes and tall trees to provide a diversity of species. Try to mirror the local vegetation community where possible.

C Remnant vegetation on steep hillside – vegetation to be retained and managed to minimise fire hazard and weed invasion. Be careful not to cause erosion by disturbing the soil surface at vulnerable times of the year.



D Site of farm sheds, parking area and future winery/tasting area – location provides an opportunity to design the tasting room. Plant border vegetation to provide insectary and/or raptor bird habitat and add to the attractiveness of the dam.

E House site set below top of the hill and its outline absorbed into the backdrop of trees.

F Revegetation around the house site, preferably using indigenous plants.

G Remnant vegetation on steep hillside – vegetation to be retained and managed to minimise fire hazard and prevent noxious weed invasion.

H Planting to shield vines from prevailing winds and to link area of remnant vegetation.

I Headlands provided at the end of the vine rows. Consider the use of low lying native grasses in trafficable areas of the vineyard to ensure there is ground cover. Volunteer weed growth is preferable to bare soils.

J Space left for future buffer plantings in the future.

Figure 22. Some of the suggested placement locations of insectary plantings.

Principles of plant selection

- **Biodiversity**: You may not see every species that you plant in the first year. Some 'pioneer' species help build soil conditions that will help other plants thrive in the future. Some seeds can lie dormant for years before germination conditions are optimal for establishment.
- **Mimic nature**: The most productive and resilient ecosystems on earth are polycultures that feature a diversity of plants with different growth habits, root architectures, light and water needs, flowering times, shapes and sizes. A diversity of plant life above ground will lead to greater microbial diversity below ground, making the whole system more resilient to disease and pest outbreaks.
- **Plant forbs (flowers)**: Providing a mix of forbs that flower throughout the year ensures a constant supply of habitat (nectar, pollen, and alternative prey), which support both predatory arthropods (and pollinators).

While grasses will often dominate, they provide limited benefits when compared to the diversity of plant functional groups available. Consider the use of low-growing, woody, prostrate ground covers and shrubs in and around the vineyard to provide provisioning services throughout the year.

Spatial movement of predatory arthropods

Movement between plants enables natural enemies to find floral resources, alternative prey/hosts, and seek refuge from adverse conditions and resource bottlenecks (Schellhorn et al., 2015) that occur when SNAP is less available.

Native perennial plants may provide valuable habitat for mobile predators (Letourneau et al., 2012), especially during winter when deciduous plants shed their leaves. Some predators are more mobile than others and have the capacity to colonise areas more quickly (Hogg and Daane, 2018).

For example:

- It is reported that minute pirate bugs and predatory thrips can disperse up to 36 metres (Irvin et al., 2018; Nicholls et al., 2001) from insectary plantings and parasitoids up to 80 metres from buckwheat refuges (Lavandero et al., 2005), while ground beetles move up to 200 metres from boundary plantings into adjacent crops.
- Spiderlings are well known for their capacity to passively colonise new areas via aerial dispersal techniques, including 'ballooning', which involves moving through the air on silken threads over large distances (Greenstone, 1990; Kevan and Greco, 2001; Simonneau et al., 2016; Venturino et al., 2006).

The direction of travel either along (favoured by microbats) or across rows will also be of interest as this will provide insights to the best location of an insectary.

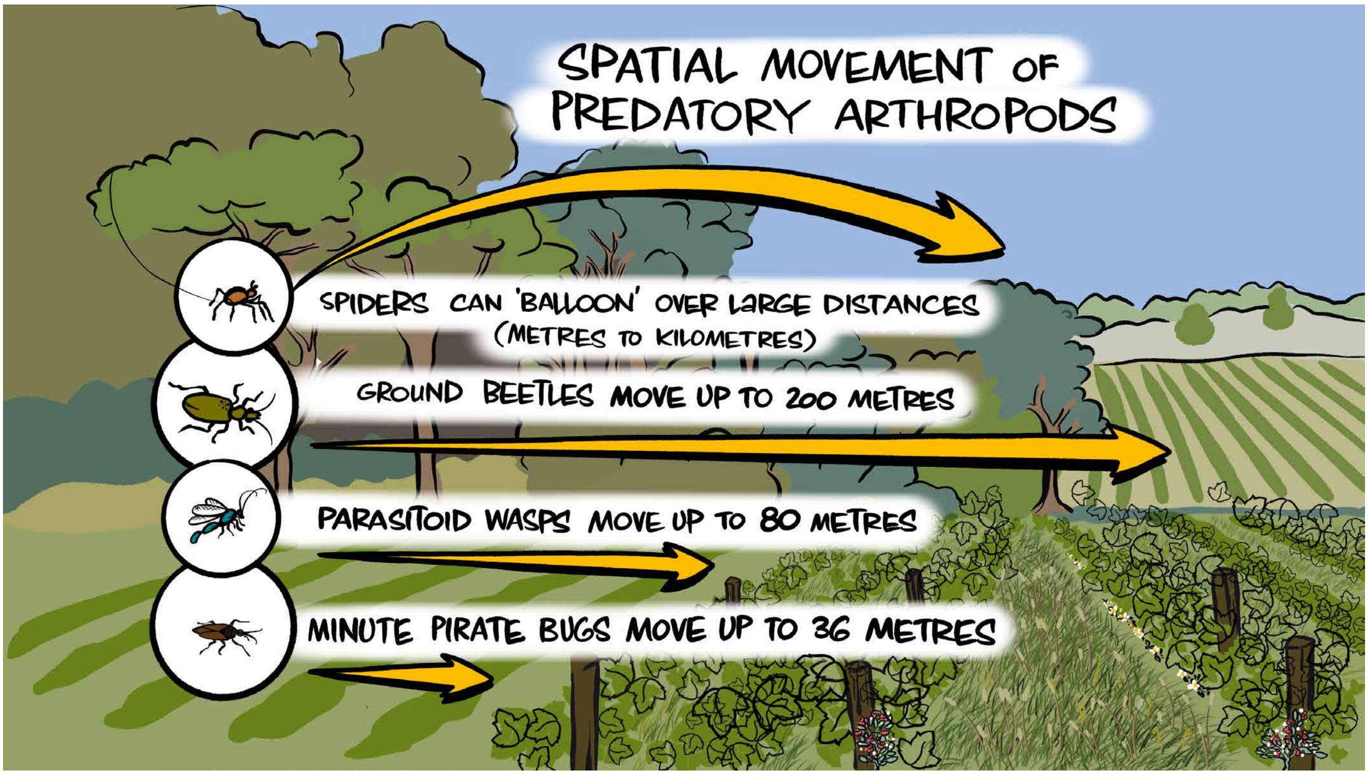


Figure 23. Examples of spatial movement of predatory arthropods.

Table 2. Capacity for functional biodiversity enhancement using native insectary plants.

Existing vineyard infrastructure and layout	Capacity for functional biodiversity enhancement
Linear rows of vines, approx. 2.5 metres apart with ground cover (volunteer weeds or cover crops) in the midrow.	Establish select wildflower, native grass mixes and/or prostrate-growing woody ground covers to trial in the mid-row and under-vine areas.
Headlands (~10 to15 metres) bare compacted soil or weedy species.	Establish low-growing shrubs adjacent to strainer posts.
Stakes (thin metal, plastic, or wooded stakes to support plant growth).	Repurpose potential waste products like PVC tubes or conduit into shrub stakes.
Grow tubes / plant guards for the first 3 to 4 years (come in a range of styles and colours).	Repurpose old vine guards into shrub guards. Cut down to size and reuse to reduce waste stream.
Cultivated or sprayed (herbicide) strips of ground (60 to 80 cm) under vines	Establish grass/wildflower mixes and/or selected herbaceous prostrate-growing ground cover plants to trial in the under-vine areas to reduce the need for herbicide application and enhance soil health and insectary habitat.
Deer, rabbit or kangaroo fencing surrounding the vineyard.	Establish climbing native insectary plants to help screen and improve the multi-functionality of man-made structures.
Surrounding and/or internal hedges, trees, and vegetation	Enhance the biodiversity and functionality of existing shrubs and trees found in association with vineyards by focusing on native and diverse supplementary flora (different flowering times and heights).
Vineyard equipment passes (tractors with sprayers, mowers, cultivators, trimming equipment).	Reduce the need for vineyard intervention by enhancing the functional biodiversity, ecosystem services and resilience of production systems.
Regular intervention by people in the vineyards to control pests and weedy species.	Reduce the chemical intervention needed by providing habitat for predatory arthropods, microbats, and birds that can contribute to the biocontrol of insect pests and reduce the need for herbicides by planting perennial native plants in the mid and under vine.
Windbreaks and fence lines	Enhance the biodiversity and functionality of existing windbreaks by bolstering monoculture plantings with native and diverse supplementary flora. Screen man-made fence lines using native climbing insectary plants.
Access tracks (grass, hard core, gravel, concrete, bitumen) of varying lengths and contour banks.	Consider installing raised beetle banks, low-growing vegetation corridors and retaining rock piles as habitat for predatory arthropods and to slow the shedding of water (minimise erosion).
Vineyard equipment storage facilities, workshop facilities, welfare facilities, offices, spray tank wash down areas, and winery buildings.	Establish climbing native insectary plants to help screen and improve the multifunctionality of man-made structures.

Associations between predators and insectary plants

There is a growing body of information available describing the key relationships between predators in the vineyard and native insectary resources. For example:

- Wood et al. (2011) found that brown lacewings most likely breed on *Rytidosperma bipartitum*, native wallaby grass, and perhaps other grasses.
- The benefits of planting wallaby grasses are also supported by Thomson and Hoffmann (2009a) who found direct evidence of the effects of the native cover crops in enhancing predators, as predation of LBAM eggs increased when *Rytidosperma* spp., wallaby grasses, and *Chloris truncata*, windmill grass, were present.
- The author found an increase in the net number of predator morphospecies by around 27% when *Rytidosperma* spp., wallaby grasses, are planted in combination with grapevines, with wolf spiders, earwigs, brown lacewings, and predatory beetles found abundantly in association with *Rytidosperma* spp. (Retallack, 2019; Retallack et al., 2019a; Retallack et al., 2019b).
- Danne et al. (2010) found predation levels of sentinel eggs of LBAM were increased in native cover crops, which included species of wallaby grasses, windmill grass, and two species of saltbush, *Atriplex semibaccata*, berry saltbush; and *A. suberecta*, sprawling saltbush compared with introduced *Avena sativa*, oats.
- Similarly, wolf spiders are nocturnal, ground-dwelling hunters whose presence is enhanced by grassy understorey, adjacent pasture, and woody vegetation (D'Alberto et al., 2012; Thomson and Hoffmann, 2009b; Tsitsilas et al., 2006).

Coccinellid ladybird beetles, which are predators of mealybugs, whiteflies, psyllids, scale, aphids (Hodek and Honek, 2009), lepidopteran (moth), and coleopteran (weevil) immatures (Weber and Lundgren, 2009), and possibly grape phylloxera (Kogel et al., 2013), benefit from nectar and pollen resources (Landis et al., 2000).

Thomson and Hoffmann (2006b) found the distribution of spiders, predatory mites, predatory and parasitic flies, and parasitoids within a vineyard were positively influenced by native vegetation at the margins.

A plant-species-rich green cover and its appropriate management is also considered a pre-requisite for a diversified beneficial fauna in the vineyards as it also causes considerable modifications in the microbiota inhabiting soils (Burns et al., 2016).

Multi-species interactions

Plant diversification promotes diverse arthropod communities that may provide greater stability of ecosystem provisioning (Lichtenberg et al., 2017). A integrated approach to pest control is needed that embraces a range of predatory arthropods that are either present at the same time, and/or succeed one another (Waterhouse and Sands, 2001). The capacity of multiple species to provide pest control is enhanced by their capacity to attack different life stages of the pest (Cardinale et al., 2003; Holt and Lawton, 1994; Losey and Denno, 1999).

These predators may be supported by multiple insectary resources of different strata, located throughout the production landscape.

It is also reported that populations of predators may be more abundant in six-year-old than one-year-old insectary plantings (Denys and Tscharntke, 2002). This emphasises the importance of habitat age for natural enemies and possible biological control. Multi-species interactions will occur between predator and prey.

Seasonal synchrony and overwintering

The seasonality of ecosystem services can be extended by planting a range of suitable native perennial plants that provide floral resources at key times. This helps to ensure habitat permanency and synchrony of provisioning services is continual throughout the year (Losey and Denno, 1999).

An understanding of the overwintering requirement of predators may be critical to ensuring that their population base is sufficiently large at the start of the following season (Horton and Lewis, 2003; Lorenzon et al., 2015; Nicholls et al., 2001; Schmidt et al., 2005; Sotherton, 1984).

Similarly, access to suitable floral resources and alternative prey via native evergreen shrubs may help to sustain predatory populations throughout the period of grape vine dormancy (Schellhorn et al., 2015).

As you can see in **Table 3**, while the individual flowering times of specific plants may be relatively short, combining several insectary plants can extend their flowering period for many months.

Table 3. Flowering phenology of *Bursaria spinosa, Leptospermum continentale, Rytidosperma* spp. and *Vitis vinifera* in the Adelaide Hills, South Australia.

Plant species	Common name	Family	Flowering period (month)							
			A	S	O	N	D	J	F	M
Vitis vinifera	grapevine	Vitaceae				●	●			
Bursaria spinosa	sweet bursaria	Pittosporaceae					●	●	●	●
Leptospermum continentale	prickly tea-tree	Myrtaceae	●	●	●	●	●			
Rytidosperma spp.	wallaby grasses	Poaceae					●			

If everlasting shrubs, sweet bursaria and prickly tea-tree are planted in combination, this provides potential flowering resources for up to eight months during the period of active grapevine growth.

The value of evergreen plants

Seasonal variation may occur between different functional groups of organisms depending on the habitat resources available. Deciduous plants, including grapevines, may create a resource bottleneck when they lose their foliage during winter. We recommend including evergreen plants in all planting. Luckily, Australian native plants tend to be evergreen and provide year-round cover.

Manipulating the structure and habit of insectary plantings

It may be possible to manipulate the flowering time, structure, and habit of insectary plants. For example:

- Mowing of grass swards can be used to manipulate the timing of flowering and the provision of pollen for predators, such as predatory mites (Smith and Papacek, 1991).
- Mowing of alternative rows can be used to provide habitat and shelter for predators, including spiders that live and reproduce in long grass (Bernard et al., 2006a; Wood et al., 2011). Alternatively, grasses can be slashed to a minimum height of 10 cm to preserve habitat.
- It is often possible to prune or hedge woody plant species to induce a density of flower clusters or encourage a compact habit. Some species may also provide concurrent flowering over several months.
- It may also be possible to use species with spiky leaves or shoots to create a bio-hedge as a passive barrier to deter people from entering the vineyard as a duel (bio)security and (bio)diversity hedge.

Figure 24. Native plants trimmed to produce a hedge, examples clockwise from top left *Westringia fruiticosa*, coastal rosemary, at The Wetlands Vineyard, Tatachilla, SA; saltbush, Loxton; *Callistemon* sp., red bottlebrush, Pauletts Wines, Clare Valley, SA; and *Syzygium* sp., lilly pilly at Scarborough Wine Co, Hunter Valley NSW [Photos: Mary Retallack].

Figure 25. Examples of climbing and screening plants include *Hardenbergia violacea*, native lilac (left), and *Billardiera cymosa*, sweet apple-berry, and *Clematis microphylla*, old man's beard growing along the dam wall at Windsong Wines, Langhorne Creek South Australia (right) [Photos: Mary Retallack].

Potential drawbacks of using natives as insectary plants

There are several potential drawbacks of using native perennial plants. For example:

- The time taken to establish woody plants may take several years but once they are established, they may last for decades and are adapted to the local area.
- Floral provisions and shelter may be low compared to annuals in the first year until perennial plants are well established (Isaacs et al., 2009) in year two or three.
- It may be difficult to source seeds locally, or source native seeds of local provenance in commercial quantities. However, while the initial outlay may be expensive, the initial costs can be amortised over the life of the planting, and it is likely they will provide multiple ecosystem benefits.
- Seed may have low germination and viability and should be tested if sourced from a reseller.

ASSUMPTIONS ABOUT NATIVE INSECTARY

In summary, the following assumptions regarding the interactions of arthropods with native insectary plants have been made based on the information above:

- **Predators will naturally occur in remnant vegetation and vineyards in different abundances and diversities.**
- **Natural enemies will benefit from the provision of insectary plantings.**
- **Native plant species will vary in their capacity to offer provisioning services to different predatory arthropods.**
- **Insectary plantings will attract different natural enemies at different times of the year, and this will depend on their capacity to provide the required provisioning services.**
- **The strategic use of native insectary plantings, both spatially and temporally, is important to deliver these services when they are needed.**
- **Natural enemy abundance will decline with greater distance away from insectary plantings.**
- **The capacity of insectary plants to provide provisioning services will increase as they reach maturity.**
- **The capacity of natural enemies to control vineyard pests will differ and will be dependent on host and prey densities.**
- **Multi-species interactions will occur between natural enemies and prey species.**
- **The biological control provided by generalist predators will differ depending on the resources available, vineyard management practices employed, and the seasonal conditions experienced.**

SECTION 4:

FAUNA

HIGHER ORDER PREDATORS

Predatory birds

Raptor birds of prey

Predatory birds, such as barn owl, goshawk, sparrowhawk, Australian hobby, kestrel, kite, and boobook owl and many other species, will feed on a range of lower order mammals, including birds, lizards, and/or insects. If they are territorial (and many are) they may patrol the perimeter of the vineyard and help keep fructivorous (fruit eating) birds at bay, as well as controlling rodent pest species. They are an important component of the ecological food chain and potential deterrent of pest bird species.

Figure 26. Birds of prey, brown goshawk (left), eastern barn owl (middle), powerful owl (right) [Photos: Mary Retallack].

Insectivorous birds

Insectivorous birds, such as the superb fairywren, willy wagtail, diamond fire-tail finch, golden whistler, red-rump parrot, grey fantail, and different species of treecreeper, mainly feed on insects, spiders, other invertebrates, and/or seeds and do not pose a threat in the vineyard.

Figure 27. Male red-capped robin (left) [Photo: Ian Falkenberg], male superb fairywren (middle) and kookaburra (right) [Photos: Graham Lee].

For more information, please refer to the **EcoVineyards bird guide: Understanding the ecological roles of birds in Australian vineyards**.

Insect eating mammals

Microbats

Australia is home to numerous microbat species, with weights generally ranging from 3 to 30 grams. Unfortunately, many are classified as threatened species. Most are insectivores, meaning their diet is made up of insects, including moths, flies, beetles, and mosquitoes.

Each bat is capable of eating thousands of insects each night and they play a key role in the biocontrol of pest insect species. They are also a good indicator species of ecology health.

In a recent study near Bordeaux, up to 70% of bat scats recovered tested positive for the presence of *Lobesia botrana*, European grapevine moth, and this demonstrates that they contribute towards the biocontrol of these leafroller pests (Thiery et al., 2018).

Figure 28. *Nyctophilus geoffroyi*, lesser long-eared bat (left), and *Vespadelus vulturnus*, little forest bat (right) [Photos: Colin Page Photography].

Microbats use a form of biological sonar known as echolocation to help navigate their path. As they fly, they make high frequency calls that are mostly inaudible to the human ear. By listening to the echoes these calls make, bats can build a map of their surroundings and locate their prey. Bats have good eyesight but their ability to use echolocation is a more effective way of flying around and catching small insects at night.

Bats will also use linear features, such as hedgerows and tree lines, to move around. By travelling alongside these features, they are less vulnerable to predators, like birds of prey, than if they were flying out in the open.

Supplementary habitat, including manmade bat boxes (and bricks), can also be used and are best positioned at least four metres from the ground near or in vegetation and linear features like a hedgerow, which bats rely on for navigation and food.

Researchers estimated that the savings in grape yield due to pest control from bats at similar sites could equal 595 kg/ha/year in yield, which translates to farmer savings of US$188 to $248/ha/year (Rodríguez-San Pedro et al., 2020).

Microbats can be monitored using a **Chorus acoustic monitor** with the echolocation signals then analysed using software to identify species.

It was reported that a reduction in microbat populations in New England, USA in 2006 resulted in the increase of insect numbers and subsequent insecticide use by farmers by 31%. At the same time, infant mortality in the area increased by 8% (**Science, 2024**).

For more information on microbats see the **EcoVineyards fact sheet: The role of microbats in and around vineyards**.

Echidnas

Echidnas are medium-sized, solitary monotremes (egg laying mammals) covered with coarse hair and spines. They have short, strong limbs with large claws, and are powerful diggers. Their hind claws are elongated and curved backwards to aid in digging. Echidnas have tiny mouths and toothless jaws, and feed by tearing open soft logs, anthills and the like, and licking off prey with their long, sticky tongues.

The short-beaked echidna's diet consists mostly of ants and termites, while the long-beaked species typically eat worms and insect larvae. Echidnas do not tolerate extreme temperatures and they shelter from harsh weather in caves and rock crevices.

Echidnas are found in forests and woodlands, hiding under vegetation, roots, or piles of debris. They sometimes use the burrows (both abandoned and in use) of animals, such as rabbits and wombats.

Bandicoots

A bandicoot has a long, pointed snout, large ears, a short body, and a long tail. Its body is covered with fur that can be brown, black, golden, white, or grey in colour. Bandicoots have strong hind legs well adapted for jumping. They eat a range of foods, such as insects and other invertebrates, bulbs, grasses, and fungi.

Eastern barred bandicoots, found along eastern Australia, are small, nocturnal Australian marsupials that like to live among tussock grasses.

At night they emerge to feed on underground insects, leaving small, cone-shaped (nose-shaped) holes as evidence of their visit.

However, they are seldom seen on the mainland as they are endangered and forage at night between 1 and 4 am.

Figure 29. Echidnas are occasionally found in groups in vineyards like the *Tachyglossus aculeatus setosus*, Tasmanian short-beaked echidna (left) [Photo: Hannah McKay] and the nocturnal eastern barred bandicoot (right) [Photo: City of Hobart].

Reptiles

Lizards

Lizards are cold-blooded and they need to sit in the sun to raise their temperature. Most lizards can swim. Some lizards, such as geckos and skinks, can detach their tails if they are caught by a predator. A lizard's detached tail may move independently for up to 30 minutes after it disconnects from the body. The wiggling tail segment distracts the predator, allowing the lizard to escape to freedom.

There are several lizards that predominantly eat insects, including skink, gecko, blue tongued lizard, shingleback lizard, and bearded dragon, which are often found in and around vineyards with quality habitat. Blue tongue and stumpy tail lizards also consume snails and slugs.

Geckos have microscopic hairs on the bottom of their feet that make them great climbers. Lizard droppings are easy to identify because they have white tips. This is due to lizards' waste elimination process where solid and liquid waste is expelled through the same opening. The white tips are crystallised uric acid.

Lizards need shelter to hide and sleep, protected from rain and predators. Stones, rocks, hollow logs, old earthenware pipes, and even broken terracotta pots can all be used to make a shelter.

Lizards use plants for shelter and consume seeds and berries. Many plant species can be used to create habitat for a range of lizards including *Myoporum parvifolium*, creeping boobialla, *Themeda triandra*, kangaroo grass, *Hardenbergia violacea*, creeping lilac, and *Kunzea pomifera*, muntries.

Figure 30. Bearded dragon, McLaren Vale (left) [Photo: Wirra Wirra Vineyards] and shingleback lizard, Adelaide Hills, South Australia (right) [Photo: Mary Retallack].

Turtles

Turtles live in freshwater habitats, including wetlands. They commonly eat insects, worms, tadpoles, frogs, small fish, crustaceans, molluscs, plankton, and carrion.

They are indicator species, which means their abundance, distribution, and health in the ecosystem are reflective of environmental conditions.

If you see a turtle you may wish to record its presence on the **turtle sat mobile app** and help support the **1 million turtles initiative**.

Figure 31. *Chelodina longicollis*, eastern long-necked turtle (left and below), and in the vineyard dam, Coonawarra, South Australia (right) [Photos: Rae Clark].

Amphibians

Frogs

Frogs are commonly found in and around creeks and rivers in dense vegetation near waterways, but sometimes occupy burrows during the dry season. The introduction of dams in vineyards has created habitat that is potentially suitable for frogs and they are occasionally found near irrigation leaks.

Frogs are a good indicator of a healthy ecosystem, and they like to eat insects, spiders, grasshoppers, crickets, snails, slugs, earthworms, and almost anything else they can capture!

Frogs have a dual life cycle, with part of their life spent in the water (as tadpoles with gills) and out of the water (as frogs with lungs). This means they are susceptible to changes both in the water and on the land, making them a very useful indicator of ecosystem health.

Figure 32. Frogs are occasionally found in the vineyard like this Limnodynastes dorsalis, western banjo frog, at Deep Woods Estate, Margaret River, WA (left) [Photo: Kate Nickels] and Litoria ewingii, southern brown tree frog, in the Limestone Coast, South Australia [Photo: Wild Game Wine].

Creating supplementary habitat

It is often necessary to incorporate ecological infrastructures, like bird boxes, perches, or bat boxes, as supplementary habitat if natural habitat, including tree hollows, are lacking. Whereas, Magpies have adapted to sit on abundant telegraph posts and fence posts that litter the landscape.

The EcoVineyards program collaborated with **Ocloc by Ocvitti** to develop predator perches for birds of prey to provide an elevated platorm and vantage point above the top of existing intermediate posts in the vineyard.

We also partnered with Seaford Rotary via their **bat box project** to manufacture microbat boxes that provide supplementary habitat where there is a lack of natural tree hollows and roosting spots.

Figure 33. Black shouldered kite using a raptor perch at Windsong Wines, Langhorne Creek, SA (left) [Photo: Barry Featherston], and microbat boxes (right) [Photo: Mary Retallack].

ARTHROPODS

Functional group: pests

Tortricidae: leaf roller moths

Tortricidae is a diverse family of moths that have a wide range of host plants (Brown et al., 2010). The larval stage (Figure 34) are called leafrollers because the caterpillars build protective feeding shelters by folding leaves over their bodies and using silk webbing to secure these structures.

***Epiphyas postvittana*, light brown apple moth (LBAM), is considered the dominant insect pest in Australian vineyards (Scholefield and Morison, 2010). Damage to grape skins caused by leafroller moth larvae creates infection sites and may predispose bunches to Botrytis and other bunch rots. Typically, there are three (spring, summer and autumn-winter) generations per year (Magarey et al., 1994).**

There are several morphological characteristics that can be used to identify larvae to the sub-family Tortricinae, including the presence of an anal comb that is used to flick away fecal pellets from their shelters (Figure 34), and is almost always present (Brown, 2011; Gilligan, 2014a; Gilligan, 2014b).

Figure 34. 1^{st} or 2^{nd} instar tortricid larva (left), 5^{th} or 6^{th} instar inside a silk refuge (middle left), folded grapevine leaf (middle right), the presence of an anal comb is used to identify tortricid larvae to family (right) [Photos: Mary Retallack].

There are no definitive morphological characters that can be used to identify Tortricidae species at the larval stage (Whittle et al., 1991). Therefore, molecular methods, such as DNA barcoding, are required to determine larval stages of Tortricidae species with confidence (Barr et al., 2011; Barr et al., 2009; Hajibabaei et al., 2006). However, a practical alternative for wine growers is to rear larvae in containers to adulthood (Figure 35). However, specialist knowledge is still required to ensure correct identification of adult moths, and parasitised larvae don't survive to the adult stage.

It is important to avoid plant species that may provide breeding sites for pest species. For example, LBAM is readily found on broad leaf weedy species, including capeweed and plantain.

Figure 35. Growers can rear tortricid larvae to determine the species once it emerges as an adult moth [Photos: Mary Retallack].

Other insect pests

There are many other insect pests that also contribute to economic damage of grapevines. For example, it was estimated in 2010 that losses of $0.5 million per year can be attributed to garden weevils, grape phylloxera, mealybugs, scales, and trunk boring insects (Scholefield and Morison, 2010).

The scale species commonly found in Australian vineyards are *Parthenolecanium persicae*, grapevine scale, and *Parthenolecanium pruinosum*, frosted scale, with several other species found periodically. Other vineyard pests include Australian grapevine moth, elephant weevil and mites (Bernard et al., 2007; Thomson et al., 2007).

Figure 36. Economically damaging pest of grapevines include Parthenolecanium persicae, grapevine scale (left), and long-tailed mealybug, Pseudococcus longispinus insects (right) [Photos: Mary Retallack].

Improving grapevine health as a deterrent to insect attack (and disease susceptibility)

One of the focuses of the EcoVineyards program is to try and eliminate the use of insecticides by focusing on an ecological and integrated approach to insect management and improving plant health rather than a reliance on chemical intervention that will often result in the death of many predatory arthropods.

One of the ways we can potentially reduce the impact of sap sucking insects (Order: Hemiptera) and other insect pests is to objectively increase plant health, which can be measured via the concentration of brix found in mature plant leaves and assessed using a refractometer in the field.

As leaf brix increases the secondary metabolites produced by the plant increase and they become less susceptible to insect and pathogen attack.

Figure 37. Leaf brix can be measured using a pair of modified vice grips to extract leaf sap and a refractometer which provides an objective measure of plant health [Photos: Mary Retallack].

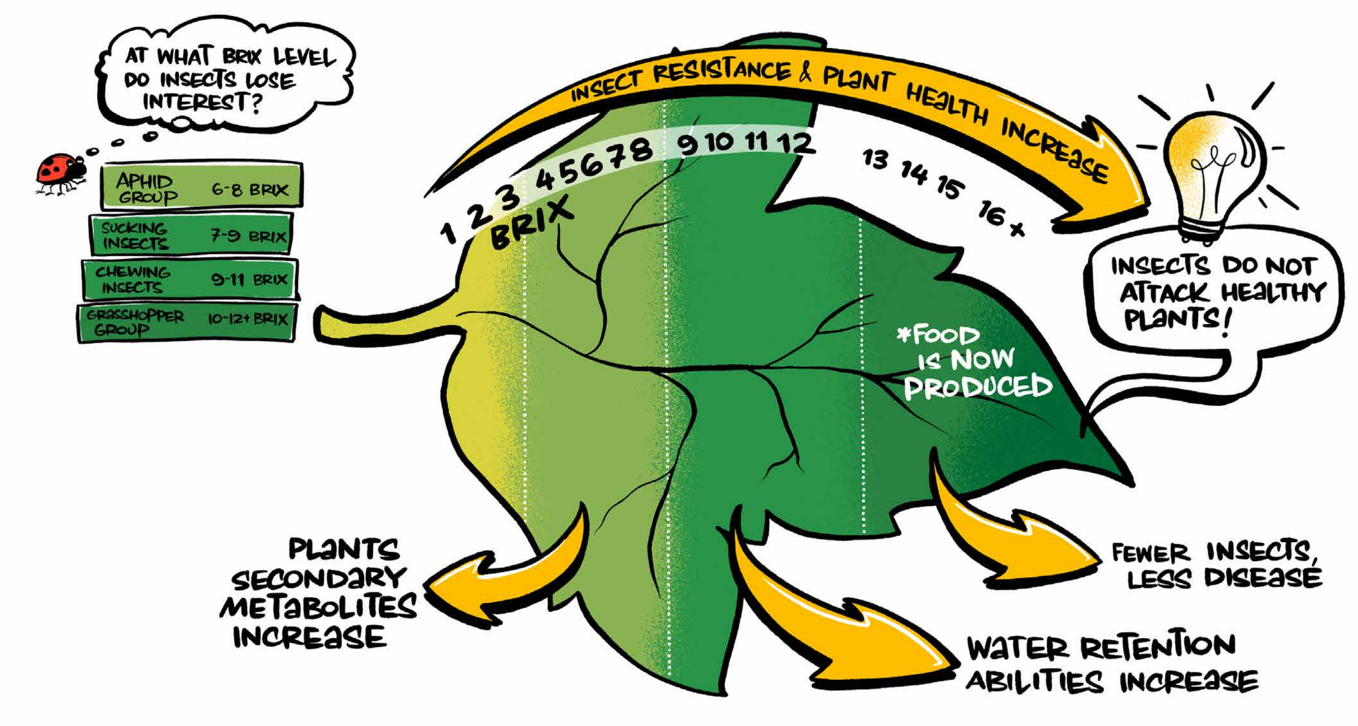


Figure 38. Leaf brix chart and generalised markers of plant health and resistance to insects and diseases.

Scale insects and mealybugs are herbivores from the order Hemiptera. They have piercing and sucking mouth parts that they use to feed on plant sap. However, they are unable to feed on plants with high brix (sugars) in the leaves (Dykstera, 2021).

The digestive system of many insects is a tube inside a tube where food is consumed via the mouth and waste products excreted at the anus. However, the digestive system of many Hemiptera insects is unique as it folds back against itself and includes a hindgut with a filter chamber that will accumulate most of the sugars and excrete them as honeydew, so it doesn't overwhelm the digestive system of the insect and kill it.

This structure allows the insects to ingest and process large volumes of plant sap. Excess water, sugars, and certain amino acids bypass most of the midgut and are shunted directly into the hindgut for excretion.

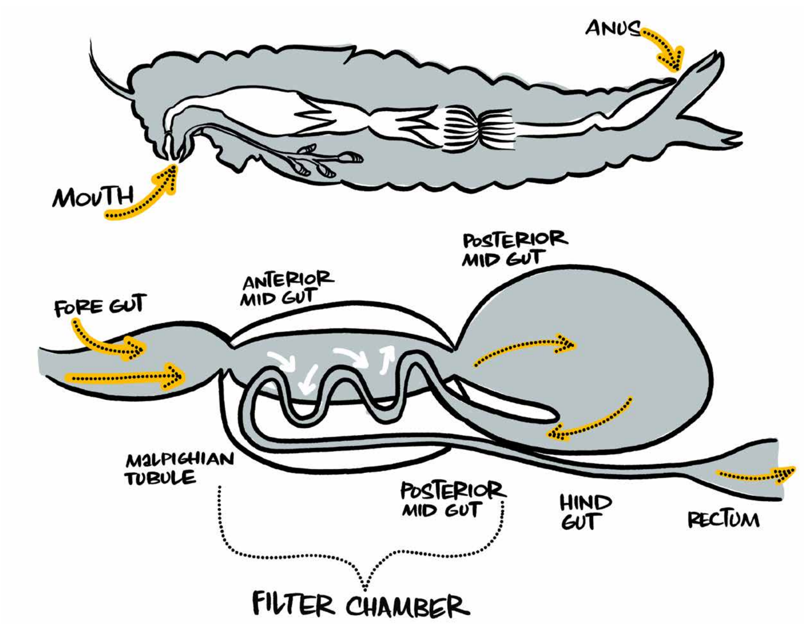


Figure 39. Insect digestive systems of a grasshopper (top) and aphid (below) highlighting the filter chamber of many Hemiptera species [Image: Thomas Dykstra].

Functional group: predators

Generalist predators feed on a range of host species and are often voracious feeders of eggs, larvae, and adult stages. Many predators, like spiders, brown and green lacewings, ladybird beetles, and predatory bugs are commonly found in vineyards (Thomson and Hoffmann, 2008; Thomson et al., 2007).

A range of generalist predators contribute to the control of LBAM (Bernard et al., 2006b) and other tortricid moths. The main predators and parasitoids of leafrollers include neuropteran larvae (lacewings), spiders, earwigs, ladybird, carabid and rove beetles, predatory Hemiptera (shield and damsel bugs), predatory Diptera (hover flies and robber flies), and parasitic wasps (Bernard et al., 2006b; Frank et al., 2007; Hogg et al., 2014; Paull, 2007; Thomson and Hoffmann, 2009a; Thomson and Hoffmann, 2010b; Yazdani et al., 2015; Yazdani and Keller, 2017). Some predators feed on leafroller eggs (Danthanarayana, 1980; MacLellan, 1973; Paull and Austin, 2006).

It is reported that up to 90% of newly hatched leafroller larvae may be killed by predators in the absence of toxic chemicals (Helson, 1939; Waterhouse and Sands, 2001).

Parasitoids

There are at least 28 known parasitoids of eggs, caterpillars, and pupae of LBAM (Paull, 2007; Paull and Austin, 2006). Trichogramma spp. wasps are only able to parasitise LBAM eggs (Glenn et al., 1997; Glenn and Hoffmann, 1997) but no other life stage. This, along with low levels of parasitism and late season activity, may naturally limit their ability to control LBAM in isolation (Bernard et al., 2006a).

However, young LBAM instars can be parasitised by *Dolichogenidea tasmanica* (Hymenoptera: Braconidae), but parasitism is only possible up to and including the third instar (Yazdani et al., 2015), whereas *Gonozius* spp. (Hymenoptera: Bethylidae) can parasitise third and fourth stage instars (Danthanarayana, 1980).

Figure 40. Conservation biological control of LBAM is provided by *Oechalia schellenbergii*, predatory shield bug, consuming a leafroller larva (left) [Photo: Mary Retallack] and *Dolichogenidea tasmanica*, braconid wasp, parasitising a leafroller larva (up to 3rd instar) (right) [Photo: Michael Keller].

Predatory arthropods found in association with native evergreen shrubs

When native evergreen shrubs were assessed the richness (diversity) of predator morphospecies was nearly double the number found in association with grapevines (Retallack et al, 2019).

It may be possible to increase the functional diversity of predatory arthropods by more than 3x when native evergreen shrubs are present versus grapevines only (Retallack et al., 2019c).

Native evergreen shrubs

Sixty-seven morphospecies of predatory arthropods were found in association with sweet bursaria, including brown and green lacewings, spiders, predatory and parasitic wasps (Chalcid, Ichneumonid, Proctotrupoid, Tiphiid and Vespoid), predatory shield bugs, and many other 'good bugs' (Retallack, 2019).

Figure 41. *Micromus tasmaniae*, brown lacewing; *Mallada signatus*, green lacewing larva; jumping spider (Salticidae); and flower or crab spiders (Thomisidae) ambush their prey (clockwise from top left) [Photos: Mary Retallack].

Prickly tea-tree provides habitat for natural enemies that are attracted to sources of nectar and pollen, such as predatory and parasitoid wasps (Chalcid, Ichneumonid, Proctotrupoid, Tiphiid and Vespoid), lacewings, spiders, and other predators. At least 63 morphospecies of predatory arthropods were found in association with prickly tea-trees and many species overlapped with sweet bursaria.

Figure 42. *Cermatulus nasalis*, glossy shield bug [Photo: Landcare Research NZ]; *Oechalia schellenbergii*, predatory shield bug; *Harmonia conformis*, common spotted ladybird beetle; and *Gminatus australis*, orange assassin bug (clockwise from top left) [Photos: Mary Retallack].

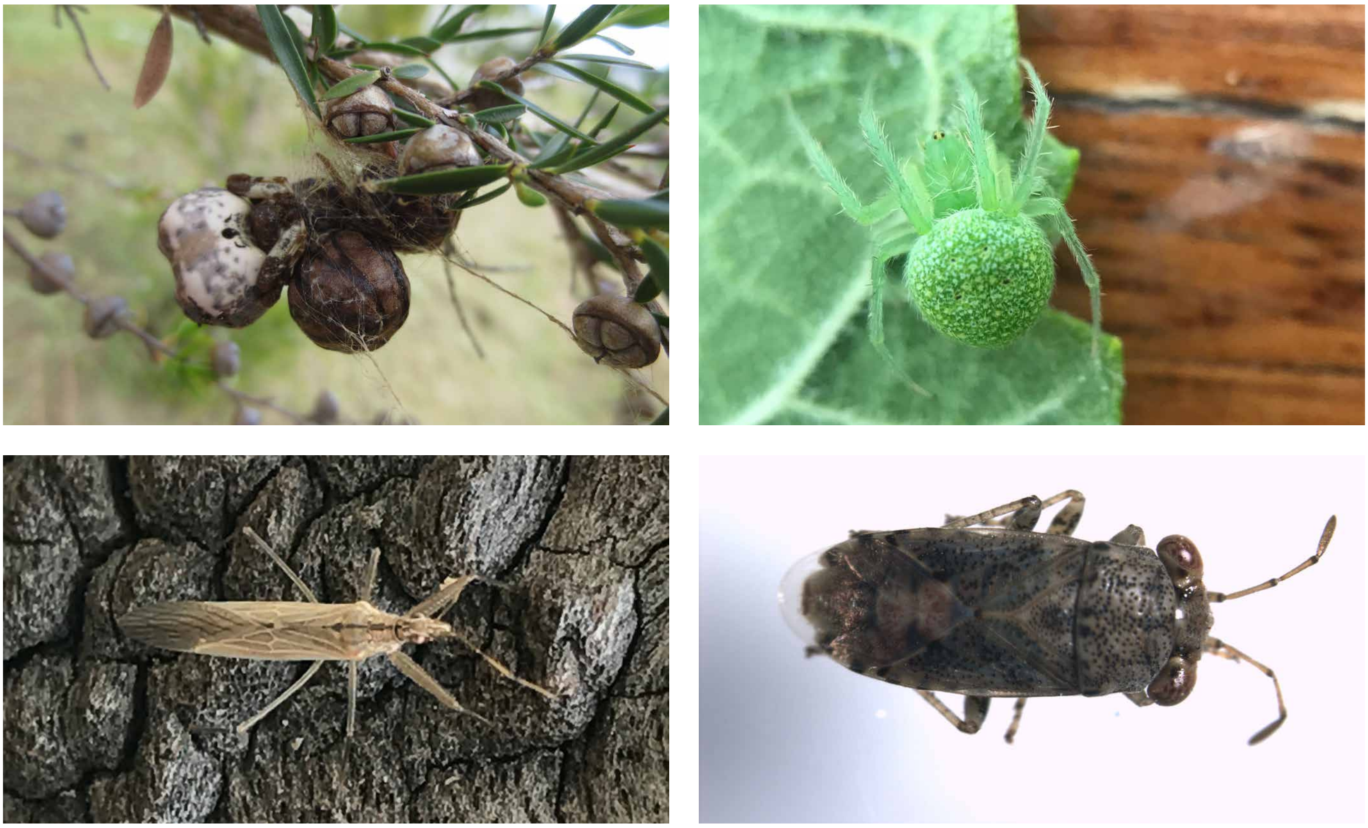


Figure 43. *Celaenia excavate*, bird-dropping spider; *Araneus circulissparsus*, speckled orb-weaver; *Nabis kinbergii*, Pacific damsel bug; *Geocoris* spp., big-eyed bug (clockwise from top left) [Photos: Mary Retallack].

Predatory arthropods found in association with native wallaby grasses

Recent research by Retallack (2019) found at least 38 morphospecies (visually distinct specimens) of predatory arthropods were found in association with wallaby grasses, *Rytidosperma* spp., in vineyards.

Wallaby grasses provide a valuable complementarity habitat for arthropod species other than those commonly found in association with native woody perennial shrubs and may increase the net number of predator morphospecies by around 27% when planted in association with vineyards.

Wallaby grasses provide habitat for a diversity of predators with wolf spiders, brown lacewings, earwigs, glossy shield bugs, carabid beetles, parasitoid and predatory wasps (Ichneumonid, Vespoid, and Sphecidae), and carabid beetles found abundantly in South Australian vineyards (Retallack et al., 2019a).

It is also reported that predation of LBAM eggs increases when wallaby grasses are present. The difference between predatory and herbivore morphospecies was 2:1 predators: herbivores (Retallack, 2019).

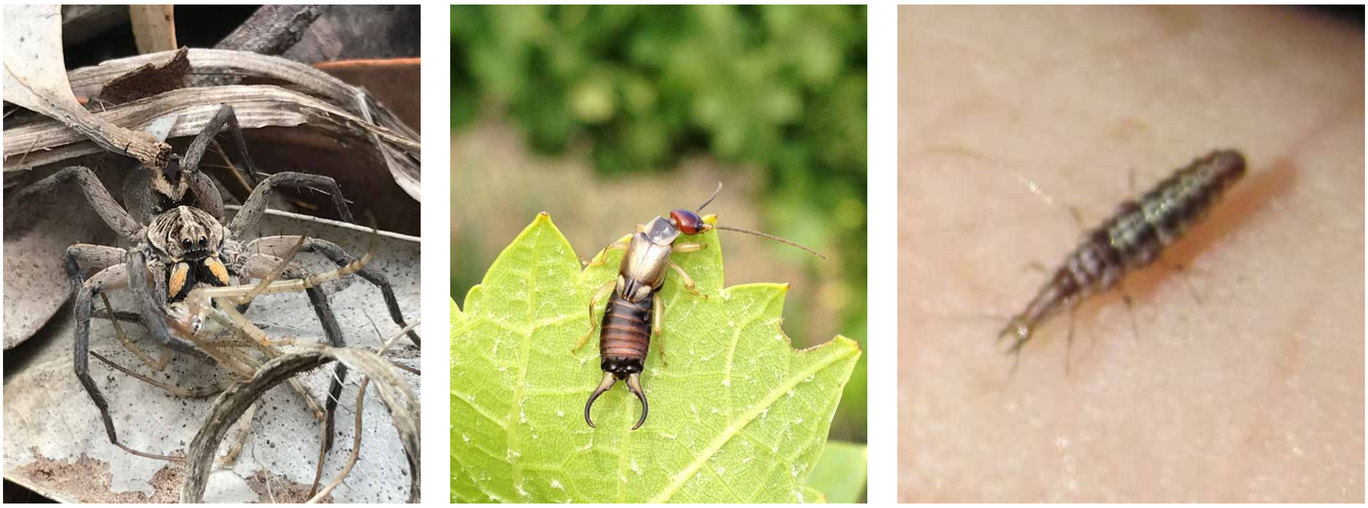


Figure 44. *Tasmanicosa* sp., garden wolf spider ; *Forficula auricularia*, European earwig; *Micromus tasmaniae*, brown lacewing larva [Photos: Mary Retallack].

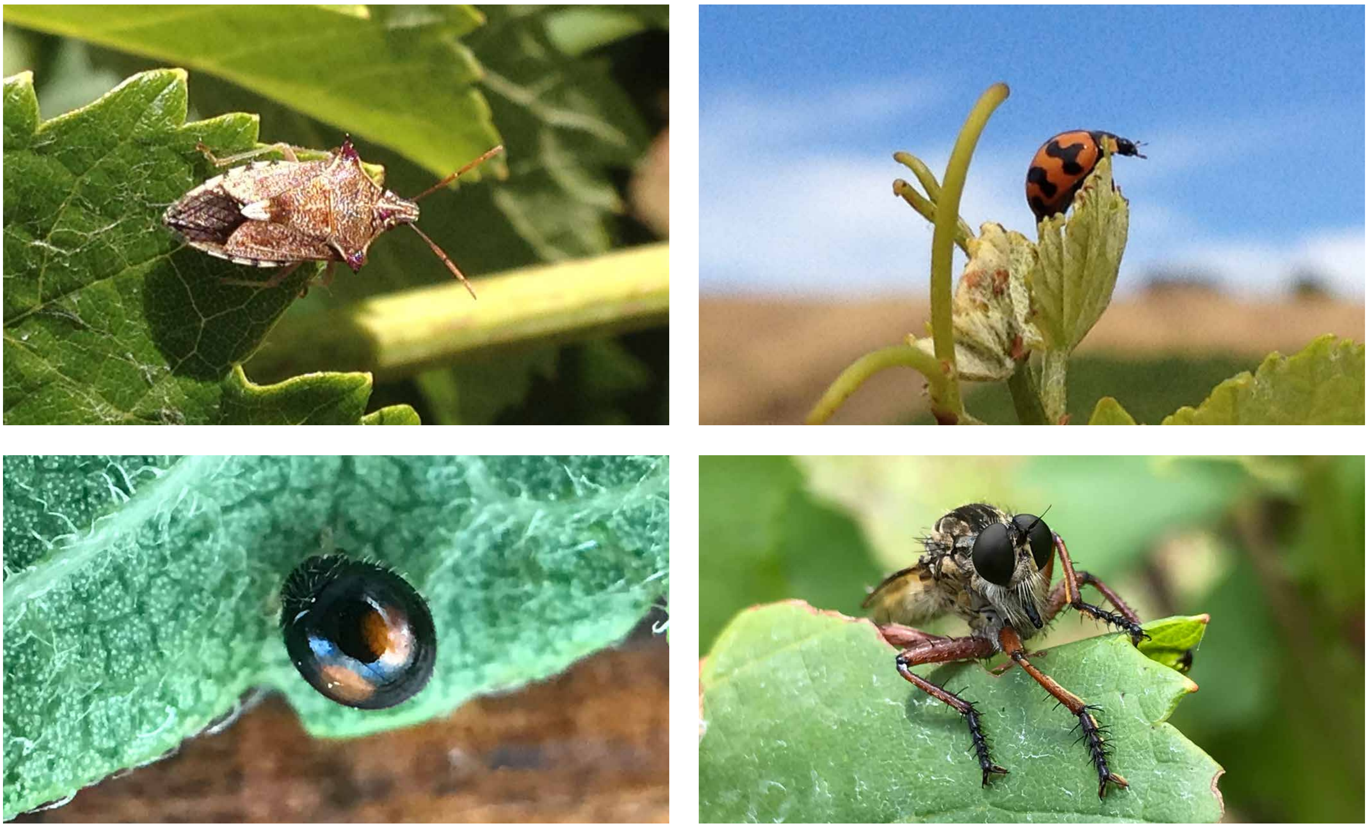


Figure 45. *Oechalia schellenbergii*, predatory shield bug; *Coccinella transversalis*, transverse ladybird beetle; *Diomus notescens*, minute two-spotted ladybird; robber fly (Asilidae) (clockwise from top left) [Photos: Mary Retallack].

Natural enemies are most abundant from October to December on wallaby grasses. This period coincides with the peak time that predators are needed for crop protection during flowering and in the lead up to harvest. The presence of predatory arthropods reduced as weather conditions became less favourable (hot and dry) and access to floral resources diminished.

For more information please refer to the **Natural predators of vineyard insect pests** booklet.

When are arthropods most active

As highlighted in **Figure 46**, arthropod activity in and around vineyards often coincides with a peak in activity in late October to mid-December, with populations declining when conditions become hotter and dryer. This will depend on each season.

It is important to note the persistence of predatory arthropods all year round while there are insectary resources and habitat available.

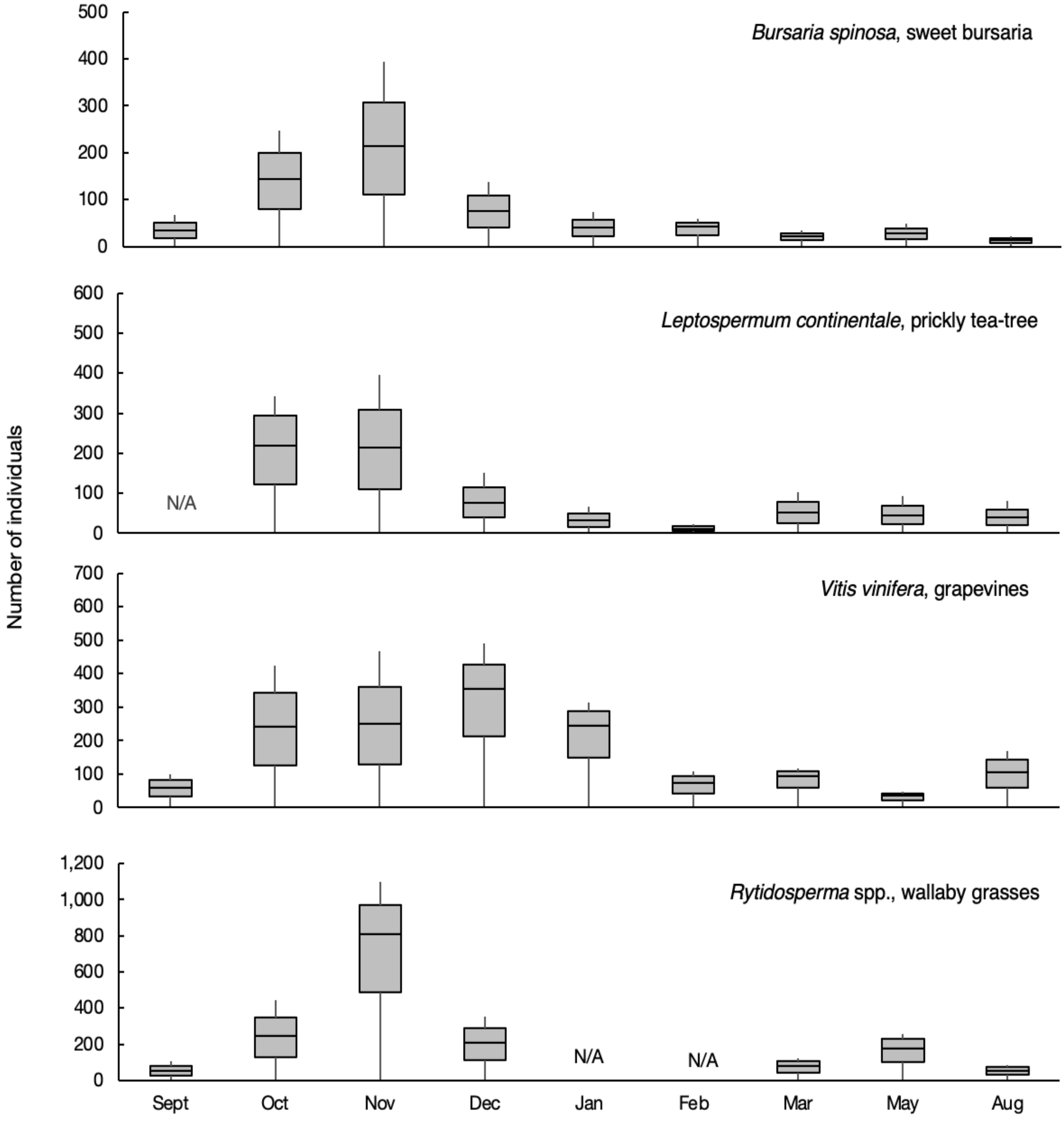


Figure 46. Temporal abundance of predator arthropods on native insectary plants and grapevines over a 12-month period (Retallack, 2019).

Biocontrol of pests and pathogens below ground

As above-ground biocontrol of pests occurs, a similar process occurs below ground and there is a myriad of macro- and micro- organisms in healthy soils that contribute to biocontrol of insect pests in and around the root systems of plants. This is another example of an ecosystem with the functional elements highlighted below in **Figure 47** (see caption for descriptions).

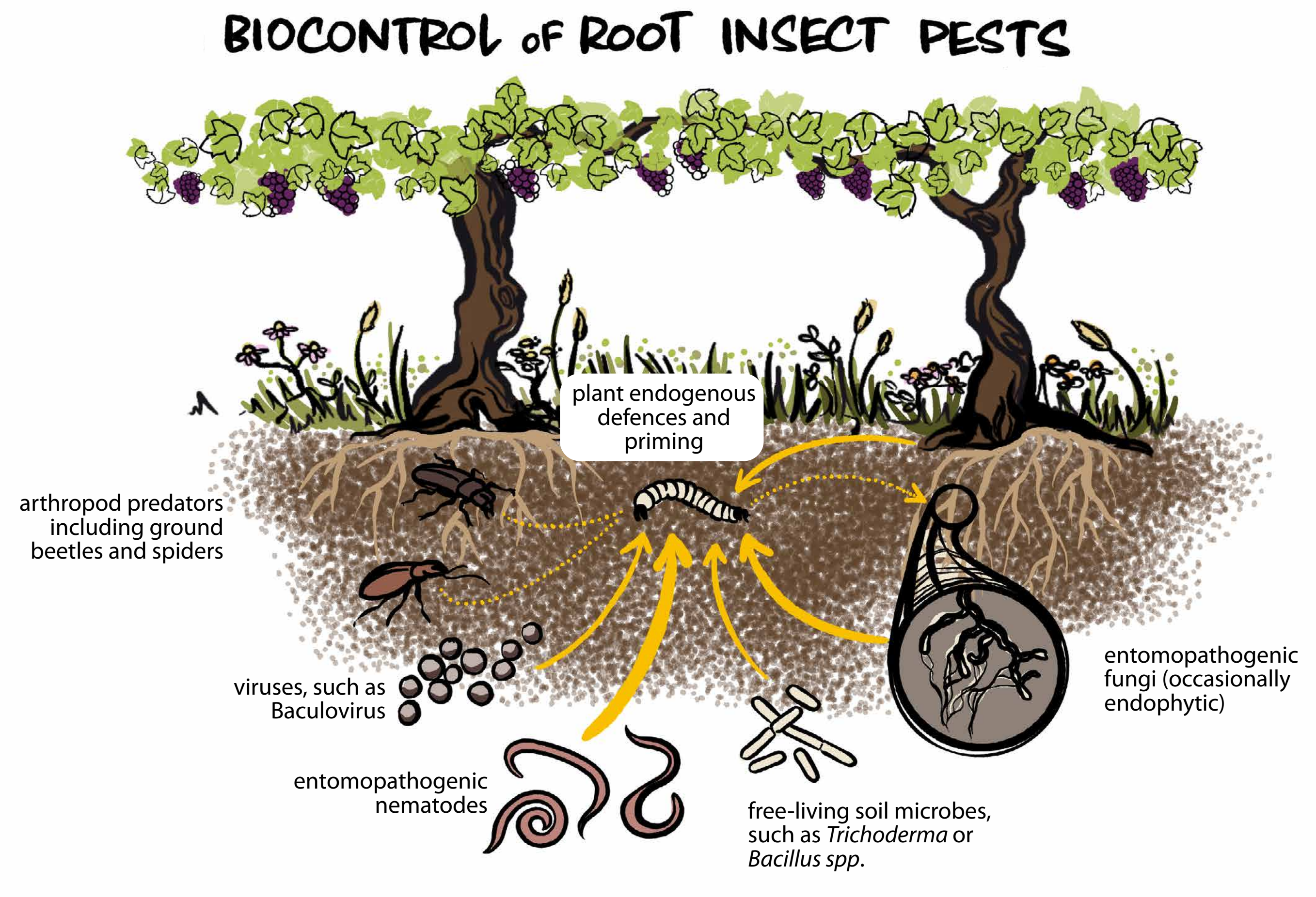


Figure 47. Biocontrol against root insect pests modified from (Kergunteuil et al., 2016).

The soil organisms that contribute to the biocontrol of root insect pests include:

- **entomopathogenic fungi (fungi that can kill or seriously disable insects)**
- **free-living soil microbes, such as *Trichoderma* or *Bacillus* spp.**
- **entomopathogenic or predatory nematodes**
- **viruses, such as Baculovirus**
- **arthropod predators, including ground beetles and spiders**
- **plant endogenous defences and priming (production of compounds like salicylic acid, jasmonic acid, and ethylene cause earlier, faster, and/or stronger responses to pathogen attack).**

Arrows represent trophic links. Different line thicknesses represent strengths of interactions, with thicker lines representing stronger potential biocontrol effectiveness than thinner lines. Dashed lines represent the currently weakest potential for biological control agents, as described in the text.

Minimising disruption in the vineyard

The overuse of pesticides may also result in a range of unintended consequences, including the development of resistance in some arthropod pests (Whalon et al., 2008), including mealybugs, scales, moths, and mites.

Pesticide application is often imprecise and it is estimated that 98% of sprayed insecticides and 95% of herbicides miss their intended target species (Miller, 2004).

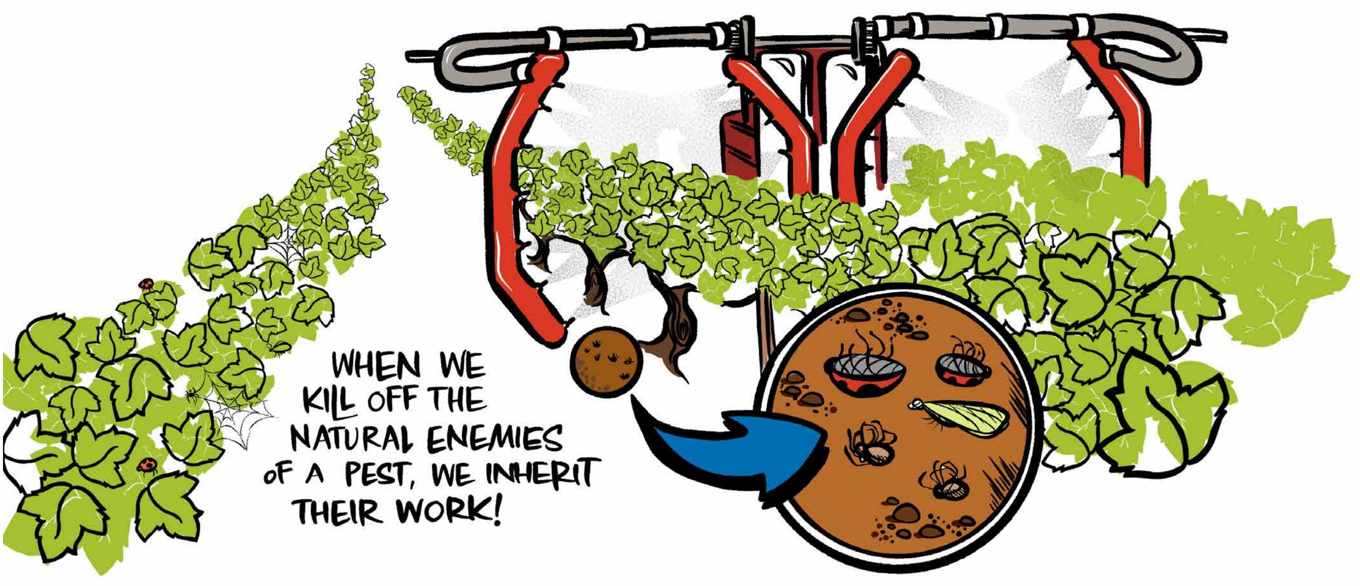


Figure 48. Pesticide application is often imprecise and it is estimated that 98% of sprayed insecticides miss their intended target species.

"*When we kill off the natural enemies of a pest, we inherit their work.*" Dr Carl Huffaker, UC, Berkley

Optimal biological control of economically damaging insect pests in vineyards can be achieved by minimising the use of broad-spectrum insecticides that may kill and often result in collateral damage to predator populations (Bernard et al., 2007). The use of non-selective pesticides should be eliminated if insectary habitat is to be established nearby (Winkler, 2005).

"*Integrated Pest Management is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimise the use of pesticides*" (FAO, 2024).

Ideally, pest control is achieved using biological control, with the targeted application of selective insecticides used to reduce pest populations to below damaging levels, only if required. Agricultural systems are typically difficult environments for predatory arthropods to thrive because of the high level of disruption.

Greater stability of arthropod populations (Landis et al., 2005; van Emden and Williams, 1974) is likely in vineyards where tillage and chemical inputs are minimised (McLaughlin and Mineau, 1995; Nash et al., 2008) and a greater diversity and complexity of insectary plants is promoted.

There are a range of factors that favour augmented biocontrol of insect pests, including cancellation of pesticide registrations, pesticide resistance, and the expansion of organic agriculture (Warner and Getz, 2008).

Biological control is one of the most important alternatives to conventional pesticide use in pest management. Biological control is free of many of the problems associated with pesticide use, such as pest resistance, environmental pollution, and worker health impacts.

There are three simple steps growers can adopt to encourage predator arthropod populations:

1. **Firstly, reduce broad-spectrum pesticide use. Only use targeted application of selective insecticides to reduce pest populations to below damaging levels if they are required.**
2. **Secondly, consider adopting a truly integrated approach to pest management that incorporates cultural and biological control as a longer-term approach to integrated pest management (IPM). Monitor populations of predatory arthropods and augment with the release of biological control agents if required.**
3. **Thirdly, incorporate suitable, locally adapted, native insectary plants to boost the presence of predators and parasitoids in and around production systems throughout the entire year.**

SECTION 5:

REPORTED AGROCHEMICAL TOXICITY TO HUMANS

AGROCHEMICAL TOXICITY

More than 70 pesticides are used in Australia that have been banned in Europe due to their effects on the environment and humans, including chlorpyrifos, fipronil, maldison (malathion), neonicotinoids, paraquat, and procymidone (The Guardian, 2022), which are still registered for use in vineyards (AWRI, 2024) but prohibited from use by some wineries.

Chlorpyrifos (activity group 1B, also includes diazinon, fenitrothion, malathion, trichlorfon)

- Chlorpyrifos is an organophosphate pesticide used to control a wide range of insect pests on produce, including wine grapes.
- The EU banned chlorpyrifos in 2019 after the European food safety watchdog linked the insecticide to brain damage in children and classified it as presumably toxic to human reproduction. In the US, the chemical has been banned for domestic use since 2000 and use on food products since 2021.

Use in Australia: The APVMA has determined that as of 30 September 2024, the continued use of chlorpyrifos on grapevines is NOT SUPPORTED. A 12-month phase-out period has begun, where products bearing the previously approved labels may continue to be sold and used. After 30 September 2025, it will be an offence to have possession or custody of, supply, or to use the cancelled active constituents, chemical products and products bearing the previously approved labels (APVMA 2022a, 2024a).

Fipronil (activity group 2B)

- Fipronil is a broad-spectrum insecticide used in agriculture. It controls insect pests in a wide range of agricultural crops, including wine grapes. Fipronil acts as a central nervous system disruptor and is toxic to honeybees.
- It was banned for use in agriculture in Europe in 2013.

Use in Australia: Fipronil has been under review since 2011. A preliminary review proposed continuing its use on seed and in flea treatments. The review is still under way (APVMA, 2024b).

Malathion (activity group 1B, also includes chlorpyrifos, diazinon, fenitrothion, trichlorfon)

- Malathion, also known as maldison, is a broad-spectrum organophosphate insecticide used in veterinary and agricultural products. Exposure to malathion can cause poisoning and rashes. It may be an endocrine disruptor and has been classified as a possible carcinogen by US authorities.
- Malathion has been banned in the EU since 2007. Use is permitted in the US.

Use in Australia: The regulator has been reviewing malathion since 1994. It was prioritised in 2003 due to public health concerns, but the review remains incomplete and the chemical is still sold for household use (APVMA, 2022b).

Neonicotinoids (activity group 4A, also includes acetamiprid, clothianidin)

- This family of pesticides has been blamed for the dramatic fall in the numbers of honeybees and they are also harmful to frogs. Neonicotinoids are considered by the UNEP's Global Chemicals Outlook to be one of 11 groups of chemicals that 'warrant urgent international concerted actions'.
- Neonicotinoids were banned in the EU in 2018.

Use in Australia: Australia is reviewing the use of neonicotinoids with some draft assessments imminent, and decisions were expected in 2023 (APVMA, 2023).

Paraquat (activity group 22, previously L, also includes diquat)

- Paraquat is a highly poisonous and non-selective herbicide. Ingestion of even small amounts can lead to heart, kidney, and liver failure, as well as lung scarring and, ultimately, death. Symptoms of poisoning include nausea, vomiting, abdominal pain, and diarrhoea.
- Paraquat has been banned in the EU since 2007 and its use is limited to licensed users in the US.

Use in Australia: Paraquat is able to be sold and used by authorised users in Australia despite being banned in 50 countries, including China and Thailand. It is banned in domestic settings (APVMA, 2016).

APVMA recently completed a Technical Review of paraquat and diquat. Their proposed regulatory decisions were reported in a Special Gazette dated 30 July 2024 including that future use of these actives in vineyards is not supported. The proposed regulatory decision on paraquat was open for public consultation until October 2024 (APVMA, 2024). Following the APVMA's review of the consultation stage submissions, it is expected they will publish their final regulatory decisions in early 2025.

Following a recent story on ABC's Landline Program there has been considerable public discussion about the potential impact of paraquat on farmer health as well as a statement from the manufacturer in response to this story.

Procymidone (activity group 2, also includes iprodione)

- Procymidone is a fungicide used in vineyards. It has been found to be an endocrine disruptor that lowers male fertility and can cause feminisation in animals. It is known to disrupt androgen hormones.
- Procymidone has been banned in Europe since 2007.

Use in Australia: The regulator has reviewed procymidone, and in a draft decision in May 2022 it announced that it will continue to allow the sale of products containing the chemical (APVMA, 2022c).

Reported pesticide toxicity to predators

There is growing awareness of the dangers of chemical use. Chemicals may be harmful to the environment and human health if not managed appropriately. Cultural and biological control options can be used to reduce the level of intervention and the volume of chemical use required each season.

Off target damage to predatory arthropods can be significant and the cost of unintended consequences should be considered when spraying chemicals.

For example:

- **Dragonfly** nymphs are sensitive to chemical runoff into waterways, and exposure to copper (Tollett et al., 2009). Both adults and nymphs are susceptible to broad-spectrum insecticide exposure, including pyrethroids (Mian and Mulla, 1992).
- **Damselfly** adults and nymphs are susceptible to broad-spectrum insecticide exposure, including pyrethroids (Mian and Mulla, 1992) and fipronil (Sugita et al., 2018).
- **Predatory bugs** are particularly sensitive to carbaryl, methomyl, fipronil, indoxacarb, organophosphates, pyrethroids, and spinosad (Thomson, 2012). Residues on foliage or in plant tissues may remain toxic for many months (Biological Services, 2019).
- **Ladybird beetles** are particularly sensitive to high rates of *sulfur (≥ 400g/100 litres), carbaryl, methomyl, indoxacarb, organophosphates, and pyrethroids (Thomson, 2012). Growth regulators, such as buprofezin, are also toxic (Thomson et al., 2007).
- **Rove beetles** are particularly sensitive to methomyl (Sharley et al., 2008), mancozeb (Thomson et al., 2007), and other broad-spectrum insecticides, particularly pyrethroids, organophosphates, and neonicotinoids.

- **Syrphid** (hoverfly) populations can be sensitive to some chemicals but their high mobility in vineyards may account for the lack of detectable effects on this group (Thomson and Hoffmann, 2006a). Collateral damage will occur if broad-spectrum insecticides are used.
- **Parasitoid wasps** are particularly sensitive to high rates of *sulfur (≥ 400g/100 litres), clothianidin, carbaryl, methomyl, fipronil, indoxacarb, organophosphates, pyrethroids, and spinosad (Thomson, 2012). Delaying the release of Trichogramma wasps until six days after spraying with sulfur will reduce adverse effects on released organisms (Thomson et al., 2000).
- **Ants** are sensitive to chlorpyrifos, diazinon, and permethrin. They have very high sensitivity to indoxacarb, clothianidin, fipronil, sulfoxaflor, and organophosphates and are highly sensitive to petroleum spray oil, chlorantraniliprole, spinosad, and methomyl (CRDC, 2019).
- **Lacewings** are susceptible to damage by pesticides, and some fungicides may be disruptive. Chlorpyrifos can persist for up to eight weeks and, along with lime sulfur, high rates of elemental sulfur and mancozeb are particularly damaging to lacewing populations (Thomson and Hoffmann, 2007).
  - Lacewings are very sensitive to carbaryl, methomyl, and pyrethroids (Thomson, 2012). They have very high sensitivity to chlorantraniliprole and spirotetramat, high sensitivity to sulfoxaflor and clothianidin (CRDC, 2019).
- **Predatory mites** are particularly sensitive to chemical sprays, including active constituents emamectin benzoate, mancozeb (Bernard et al., 2004), spinosad (direct overspray and residue), wettable sulfur (≥ 400g/100 litres), and pyrimethanil (Bernard et al., 2010).
  - Chemical residues toxic to predatory mites must have time to degrade before predatory mites are released. Synthetic pyrethroids and some organophosphates may need up to eight weeks to break down (Bugs for bugs, 2019).
- Collateral damage will occur to assassin bug, ground beetle and spider populations if broad-spectrum insecticides are used.

NB: the *sulfur (≥ 400g/100 litres) rate assumes a concentration factor (CF) of 1 or dilute spraying volumes, which have historically been based on 4 kg sulfur per hectare at water application volume of 1,000 L/ha.

There are millions of little insect workers (as well as microbats and insectivorous birds) in production systems that can provide natural biological control virtually for free if we understand how to attract and look after them!

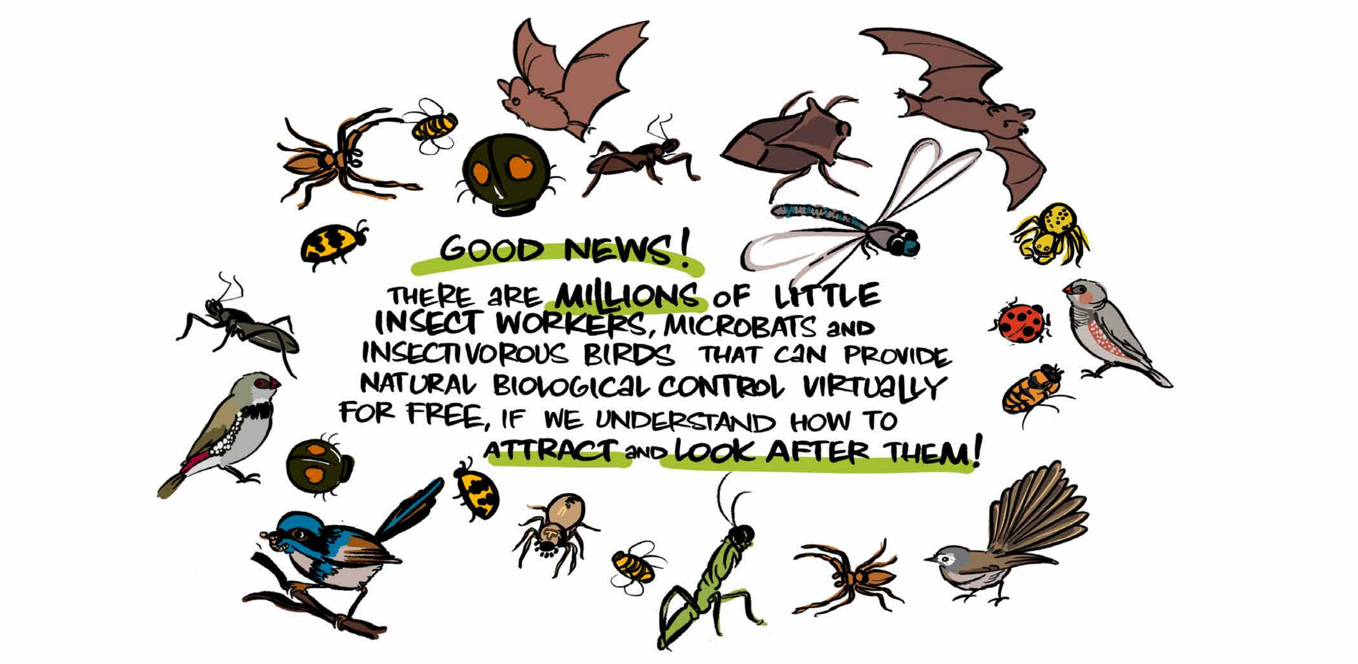


Figure 49. There are millions of little insect workers that contribute to biocontrol of insect pests.

For more details on the impact of agrochemicals on predatory arthropods see the **EcoVineyards fact sheet: Potential pesticide ecotoxicity to vineyard fauna**.

SECTION 6:

COSTS AND BENEFITS

MAKING INFORMED DECISIONS

Restored ecosystems provide a range of goods and services that, in most cases, will outweigh the costs of restoration.

Costs

Vitis vinifera, grapevines are impacted by varying levels of damage by pest insect species. *Epiphyas postvittana,* light brown apple moth, is the dominant insect pest causing damage to flower clusters and berry skins in Australian vineyards. Damage to grape skins caused by LBAM provides infection sites and may predispose bunches to bunch moulds.

Annual losses from Botrytis and other bunch rots and LBAM were estimated at $52 million and $18 million, respectively, with a combined national economic impact of $70 million per annum (Scholefield and Morison, 2010).

Whenever costs and benefits are calculated it is also important to record the downsides of a particular vineyard practice to fully realise their impacts and associated costs. Some of these costs may arise through unintended consequences, like collateral damage to predatory arthropods.

Broad-spectrum insecticides can damage populations of natural enemies, reducing the cost-effectiveness of insecticide investment if unaccounted for in treatment decisions (Zhang and Swinton, 2009). Similarly, the detrimental impact of sulfur on mycorrhizal and saprophytic fungi and copper on earthworms should be considered when making management decisions.

There are many other costs associated with off target spray events, including soil compaction when the tractor travels along the vine row, the use of fuel and associated noise, air, water pollution, and the time and resources costs associated with intervention.

Benefits

Biological control is a key component of arthropod-mediated ecosystem services, which are used to manage pests in production landscapes (Isaacs et al., 2009). Examples of benefits include:

- Biocontrol is estimated to provide five to ten times more control of pests than pesticides (Pimentel et al., 1992).
- It is reported that up to 90% of newly hatched leafroller larvae may be killed by predators in the absence of toxic chemicals (Helson, 1939; Waterhouse and Sands, 2001).
- It is estimated that the European earwig reduces insecticide applications by two to three applications per annum in apple orchards and also reduces pest damage (Cross et al., 2015).
- Predation on agricultural pests by insectivorous bats may enhance the economic value of agricultural systems by reducing the frequency of required spraying and delaying the ultimate need for new pesticides (Federico et al., 2008).
- Biodiversity and the provision of ecosystem services can be improved by at least 20% in vineyards by retaining inter-row vegetation cover versus intensive soil tillage and herbicide use (Winter et al., 2018).

- Native grasses provide a valuable complementarity habitat for arthropod species other than those commonly found in association with native woody perennial shrubs and may increase the net number of predator morphospecies by around 27% when planted in association with vineyards (Retallack, 2019).
- It may be possible to increase the functional diversity of predatory arthropods by more than 3x when native evergreen shrubs are present versus grapevines only (Retallack et al., 2019c).
- It is possible to harvest up to ten to 15 times the volume of wallaby grass seed originally sown with in the first two years of sowing, thus generating an additional income stream for the vineyard generated from the midrow area of up to $20K per hectare in good yielding seasons in addition to all the ecosystem service benefits that can be derived from native grasses.

For more information please refer to 'The cost and benefit of transitioning from an annual cereal crop to perennial native grasses' in the **BPMG on ground covers in Australian Vineyards**

Calculating the benefit of natural enemies provided by shelterbelt vegetation

There are many opportunities to increase vegetation within and around a vineyard and analysis shows that the increase in abundance of natural enemies within the vines potentially more than pays for putting vegetation in place; the value of the natural enemies in the vineyard resulting from 100 metres of vegetation is as high as $8,000 when the net gain is assessed over a 20-year period (Thomson and Hoffmann, 2010a).

The value of shelterbelt vegetation adjacent to a vineyard to pest control is estimated by calculating the value of the natural enemies provided if they were purchased from commercial suppliers.

The value of adjacent vegetation to the grower is at least $516 to $696 for each 100 metres of native vegetation shelterbelt of 4 to 10 metres in width. The cost of establishing a typical 4 to 10 metre wide shelterbelt ranges from $628 to $788 per 100 metres for a fenced shelterbelt installed by a contractor, to $47 to $88 for an unfenced shelterbelt established by grower-provided labour and machinery.

Based on the estimated costs and benefits, 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 the benefits in terms of natural enemies being derived from, conservatively, the fifth year, this represents a net gain ranging from $7,462 for the most expensive option (fenced 10 m shelterbelt installed by a contractor), to $8,203 for an unfenced 4 m shelterbelt installed by the grower (Thomson and Hoffmann, 2010a).

Table 4. Cost and benefit of establishing a 100 metre long shelterbelt (4 or 10 metres wide) over 20 years.

Established by	Fenced/ unfenced	Width (m)	Cost ($)	Benefit/year ($)[1]	Net gain first productive year [1]	Net gain over 20 years [2]
Contractor	Fenced	4	$628	$550	($78)	$7,622
		10	$788	$550	($238)	$7,462
	Unfenced	4	$104	$550	$446	$8,146
		10	$216	$550	$334	$8,034
Grower	Fenced	4	$400	$550	$150	$7,850
		10	$510	$550	$40	$7,740
	Unfenced	4	$47	$550	$503	$8,203
		10	$88	$550	$462	$7,162

1 Mean value based on a measurement in vineyards with shelterbelt widths 4 to 10 metres. 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 5 to 20 years post establishment with a single establishment cost.

APPENDIX 1:

SUGGESTED USES OF NATIVE INSECTARY PLANTS

EXAMPLES OF LOW-GROWING NATIVE INSECTARY PLANTS

Table 5. Examples of low-growing native insectary plants that may be suitable as ground covers (Retallack, 2024).

Genus	Species	Common name	Floral resource		Height (m)	Width (m)	Tolerance to frost	Flower colour	Flowering time
			Pollen	Nectar					
Atriplex	*semibaccata*^	berry saltbush	yes	no	0.4 to 0.8	1.5 to 2	resistant	insignificant	all year
Brachycome	*multifida*^	cut-leaf daisy	yes	yes	0.45	1	moderately sensitive		autumn to winter
Chrysocephalum	*apiculatum*^	yellow buttons	yes	yes	0.3	0.5 to 1	resistant		winter to spring
Dichondra	*repens*	kidney weed	yes	yes	0.1 to 0.3	1 to 5	resistant		spring to summer
Goodenia	*albiflora*	white goodenia	yes	yes	0.3 to 0.8	0.3 to 1	moderately sensitive		spring
Goodenia	*pinnatifida*	cut-leaf goodenia	yes	yes	0.4	0.1	moderately sensitive		spring to summer
Kennedia	*prostrata*^	running postman	yes	yes	0.1	1.5 to 4	moderately sensitive		winter to spring
Kunzea	*pomifera*	muntries	yes	yes	0.2	2 to 4	moderately sensitive		winter to spring
Microlaena	*stipoides*^*	weeping grass	yes	no	0.1 to 0.7	0.2 to 1	moderately sensitive		spring to summer
Myoporum	*parvifolium*^	boobialla	yes	yes	0.3	3	resistant		spring to summer
**Rytidosperma*	*fulvum*^	wallaby grass	yes	no	0.4 to 0.7	0.5	resistant		spring to summer
Scaevola	*aemula*	fairy fan flower	yes	yes	0.3 to 0.5	0.3 to 1	moderately sensitive		all year
Scaveola	*albida*^	purple fan flower	yes	yes	0.3 to 0.6	0.6 to 1	resistant		all year
Viola	*hederacea*^	native violet	yes	yes	0.2	1 to 4	resistant		all year
Vittadinia	*cuneata*	fuzzy New Holland daisy	yes	yes	0.1 to 0.4	0.3	resistant		all year
Vittadinia	*hispidula*	hairy daisy	yes	yes	0.3	0.3	resistant		all year

^ plants available commercially

* seed available commercially

Table 6. Examples of low-growing native insectary plants that may be suitable for use in mobile wicking beds (Retallack, 2024).

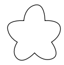
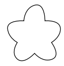
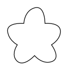
Genus	Species	Common name	Floral resource		Height (m)	Width (m)	Tolerance to frost	Flower colour	Flowering time
			Pollen	Nectar					
Astroloma	*humifusum*	native cranberry	yes	yes	0.5	1.5	resistant		autumn to winter
Atriplex	*semibaccata^*	berry saltbush	yes	no	0.4 to 0.8	1.5 to 2	resistant	insignificant	all year
Bossiaea	*prostrata*	creeping bossiaea	yes	yes	0.3	0.3	sensitive		spring to summer
Brachycome	*multifida^*	cut-leaf daisy	yes	yes	0.6	0.6	moderately sensitive		autumn to winter
Brachycome	*paludicola*	swamp daisy	yes	yes	0.6	0.6	moderately sensitive		spring to summer
Calocephalus	*citreus*	lemon beauty heads	yes	yes	0.2 to 0.5	0.3 to 1	resistant		summer
Carpobrotus	*rossii^*	pigface	yes	yes	0.1	2	resistant		winter to summer
Chrysocephalum	*apiculatum^*	yellow buttons	yes	yes	0.3	0.5 to 1	resistant		winter to spring
Correa	*alba (prostrate form)^*	white correa	yes	yes	0.3	1 to 1.5	moderately sensitive		autumn to winter
Dichondra	*repens*	tom thumb	yes	yes	0.1 to 0.3	1 to 5	resistant		spring to summer
Goodenia	*albiflora*	white goodenia	yes	yes	0.3 to 0.8	0.3 to 1	moderately sensitive		spring
Goodenia	*pinnatifida*	cut-leaf goodenia	yes	yes	0.4	0.1	moderately sensitive		spring to summer
Kennedia	*prostrata^*	running postman	yes	yes	0.1	1.5 to 4	moderately sensitive		winter to spring
Kunzea	*pomifera*	muntries	yes	yes	0.2	2 to 4	moderately sensitive		winter to spring
Myoporum	*parvifolium^*	boobialla	yes	yes	0.3	3	resistant		spring to summer
Ranunculus	*lappaceus*	common buttercup	yes	yes	0.5	0.5			spring to summer
Scaevola	*aemula*	fairy fan flower	yes	yes	0.3 to 0.5	0.3 to 1	moderately sensitive		all year
Scaveola	*albida^*	purple fan flower	yes	yes	0.3 to 0.6	0.6 to 1	resistant		all year
Viola	*hederacea^*	native violet	yes	yes	0.2	1 to 4	resistant		all year
Vittadinia	*cuneata*	fuzzy New Holland daisy	yes	yes	0.1 to 0.4	0.3	resistant		all year
Vittadinia	*hispidula*	hairy daisy	yes	yes	0.3	0.3	resistant		all year

^ plants available commercially

* seed available commercially

Examples of native insectary shrubs

Table 7. Examples of low-growing native insectary shrubs that may be suitable adjacent to strainer posts and on beetle banks (Retallack, 2024).

Genus	Species	Common name	Floral resource		Height (m)	Width (m)	Tolerance to frost	Flower colour	Flowering time
			Pollen	Nectar					
Atriplex	*cinerea^*	grey saltbush	yes	no	1 to 2	2 to 3	resistant	insignificant	all year
Atriplex	*paludosa^*	marsh saltbush	yes	no	1 to 1.5	1 to 2	resistant	insignificant	all year
Banksia	*spinulosa^*	hairpin banksia	yes	yes	2 to 3	2 to 5	resistant		autumn to winter
Bossiaea	*cinerea^*	showy bossiaea	yes	yes	1.5	1	sensitive		winter to spring
Bursaria	*spinosa^*	sweet bursaria	yes	yes	2 to 4	1 to 3	resistant		summer to autumn
Callistemon	*rugulosus^*	scarlet bottlebrush	yes	yes	2 to 4	3 to 4	resistant		summer
Correa	*alba^*	white correa	yes	yes	1 to 1.5	1 to 1.5	moderately sensitive		autumn to winter
Correa	*glabra^*	native fuschia	yes	yes	1 to 1.5	1 to 1.5	moderately sensitive		autumn to spring
Correa	*reflexa^*	native fuschia	yes	yes	0.5 to 3	1 to 2	moderately sensitive		autumn to spring
Dillwynia	*cinerascens^*	grey parrot pea	yes	yes	0.3 to 1.5	0.5 to 1.5	moderately sensitive	 	winter to spring
Dillwynia	*glaberrima^*	heath parrot pea	yes	yes	1 to 2	1 to 2	moderately sensitive		spring to summer
Dodonaea	*viscosa^*	sticky hop bush	yes	no	2 to 4	2 to 4	resistant	insignificant	spring to autumn
Enchylaena	*tomentosa^*	ruby saltbush	yes	no	0.3 to 1	0.5 to 1.5	resistant	insignificant	spring to summer
Epacris	*impressa^*	common heath	yes	yes	0.5 to 1	0.5	resistant		autumn to spring
Eremophila	*maculata^*	spotted emu bush	yes	yes	1	1	resistant		winter to spring
Eutaxia	*diffusa^*	spreading mallee-pea	yes	yes	0.5 to 1	1 to 1.5	moderately sensitive		spring
Goodenia	*ovata^*	hop goodenia	yes	yes	1 to 2.5	1 to 3	moderately sensitive		spring to summer
Hakea	*nodosa^*	yellow hakea	yes	yes	1 to 3	1 to 2	resistant		autumn to spring
Leptospermum	*continentale^*	prickly tea-tree	yes	yes	0.5 to 2	1 to 2	resistant		spring to summer

Genus	Species	Common name	Floral resource: Pollen	Floral resource: Nectar	Height (m)	Width (m)	Tolerance to frost	Flower colour	Flowering time
Leptospermum	*myrsinoides^*	silky tea-tree	yes	yes	1 to 4	1 to 4	resistant		spring
Leptospermum	*polygalifolium^*	common tea-tree	yes	yes	2	2	moderately sensitive		winter to summer
Prostanthera	*incana^*	velvet mint-bush	yes	yes	1 to 2.5	1.5	resistant		spring
Prostanthera	*lasianthos^*	Victorian Christmas bush	yes	yes	2 to 10	2 to 5	resistant		spring to summer
Pultenaea	*villosa^*	hairy bush pea	yes	yes	0.25 to 2.5	3	resistant		winter to spring
Pultenaea	*daphnoides^*	large-leaf bush pea	yes	yes	1 to 2	0.5 to 1	moderately sensitive		spring
Pultenaea	*gunnii^*	golden bush-pea	yes	yes	1	1	resistant		spring
Pultenaea	*hispidula^*	rusty bush-pea	yes	yes	1	1	resistant		spring to summer
Pultenaea	*scabra^**	rough bush-pea	yes	yes	1 to 3	1 to 2	resistant		spring
Rhagodia	*parabolica^*	fragrant saltbush	yes	no	1.5 to 3	2 to 5	resistant	insignificant	all year
Rhagodia	*spinescens^*	spiny saltbush	yes	no	1	2	resistant	insignificant	spring to summer
Westringia	*westringia^*	coastal rosemary	yes	yes	2	2	resistant		spring to winter

^ plants available commercially

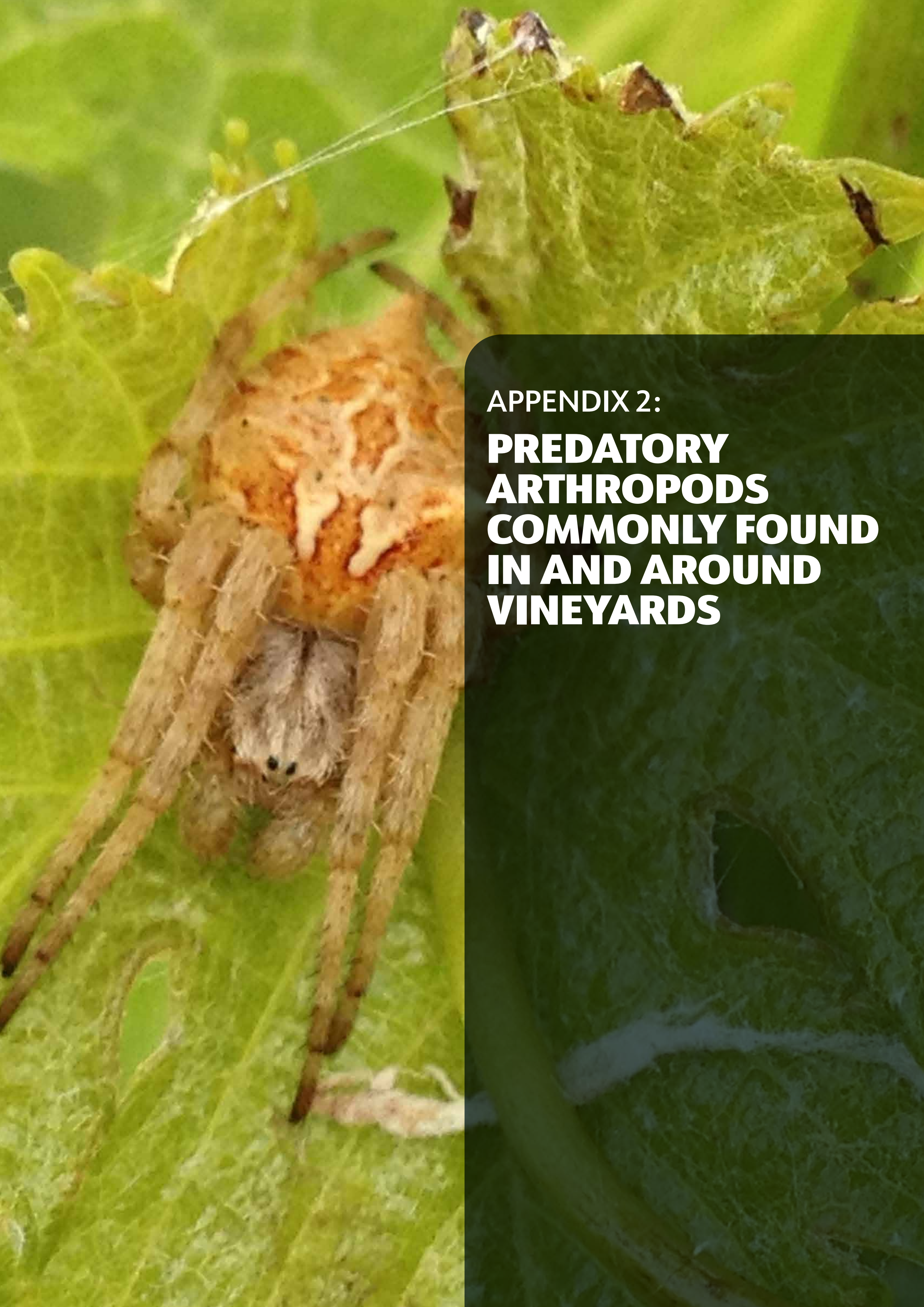
* seed available commercially

Examples of native insectary climbing plants

Table 8. Examples of native insectary climbing plants that may be suitable around the vineyard to act as screening plants along fence lines and shed walls (Retallack, 2024).

Genus	Species	Common name	Floral resource: Pollen	Floral resource: Nectar	Height (m)	Width (m)	Tolerance to frost	Flower colour	Flowering time
Billardiera	*cymosa*	sweet apple-berry	yes	yes	climber	1 to 4	moderately sensitive		spring
Clematis	*microphylla*	small-leaved clematis	yes	yes	climber	1 to 2	moderately sensitive		winter to summer
Hardenbergia	*violacea*	native lilac	yes	yes	1 to 2	1 to 2	moderately sensitive		winter to spring

Always check to see if these species are appropriate for your region. For more information on native plant lists please refer to the EcoVineyards website knowledge hub and view the regional plant species lists.



APPENDIX 2:

PREDATORY ARTHROPODS COMMONLY FOUND IN AND AROUND VINEYARDS

Predator taxa	Genus and species	Common name
INSECTA		
ODONATA		dragonfly
DERMAPTERA		
Forficulidae	*Forficula auricularia*	European earwig
MANTODEA		
HEMIPTERA		
Anthocoridae	*Orius spp.*	minute pirate bug
Nabidae	*Nabis kinbergii*	Pacific damsel bug
Pentatomidae	*Cermatulus nasalis*	glossy shield bug
	Oechalia schellenbergii	predatory shield bug
Reduviidae	*Coranus sspp.*	brown assassin bug
	Coranus granosus	
	Emesinae spp.	thread-legged bug
	Gminatus australis	orange assassin bug
	Peirates spp.	black ground assassin bug
	Pnirsus cinctipes	
HYMENOPTERA		parasitoid wasp
NEUROPTERA		
Chrysopidae	*Mallada signatus*	green lacewing
Hemerobiidae	*Micromus tasmaniae*	brown lacewing
Mantispidae		mantid lacewing
COLEOPTERA		
Anthicidae		ant-like flower beetle
Cantharidae		soldier beetle
Carabidae	*Geosccapitus spp.*	
Cleridae		
Coccinellidae	*Coccinella transversalis*	transverse ladybird beetle
	Cryptolaemus montrouzieri	mealybug destroyer ladybird
	Diomus notescens	minute two-spotted ladybird
	Eleale spp.	checkered beetle
	Harmonia conformis	common spotted ladybird
	Scymnus spp.	
Melyridae	*Dicranolaius bellulus*	red and blue beetle
Staphylinidae		rove beetle
DIPTERA		
Syrphidae		hoverfly
Asilidae		predatory robber fly
ARACHNIDA		
ACARI	*Phytoseiulus spp.*	predatory mite
ARANEAE		

Predator taxa	Genus and species	Common name
Araneidae	*Arkys spp.*	triangular spider
	Celaenia spp.	bird-dropping spider
	Eriophora spp.	orb weaving spider
Deinopidae		net-casting spider
Dysderidae		woodlouse or slater hunters
Gnaphosidae		ground spider
Linyphiidae	*Erigone spp.*	money spider
Lycosidae		wolf spider
Oxyopidae		lynx spider
Philodromidae		philodromid crab spider
Pholcidae		cellar spider
Salticidae		jumping spider
Sparassidae		huntsman spider
Tetragnathidae		long-jawed spider
Theridiidae	*Latrodectus hasselti*	redback spider
Thomisidae		crab spider
Zodariidae		ant spider
PSEUDOSCORPIONES		pseudoscorpion

FURTHER INFORMATION

Check out the following resources available via the EcoVineyards program in Australia, Regenerative Viticulture Foundation and Vidacycle in the UK, and The Porto Protocol in Portugal.

Agroecology

- AFO: The 10 elements of agroecology
- IFV: Guide transition agroécologique and changement climatique en viticulture
- Real organic podcast: Miguel Altieri: Agroecology as science and social movement
- Savory Institute: Ecological outcome verification

Agroforestry

- Wine for Normal People podcast: Agroforestry, an answer to wine's biggest environmental challenges with Jean-Baptiste Cordonnier of Château Anthonic in Moulis-en-Médoc

Arthropods

- Local Land Services: Parasitoids, pollinators, predators
- Dr Mary Retallack: Natural predators of vineyard insect pests

Birds of prey

- Barn owls, Napa Valley: The secret saviors of Napa Valley's vineyards
- Wild farm alliance (barn owls and bluebirds), Napa Valley: If you build the habitat, they will come

Hedgerows

- University of California: Establishing hedgerows on farms in California
- University of California: Hedgerow benefits align with food production and sustainability goals

Insectary plants

- EcoVineyards: Journal articles on native insectary plants
- EcoVineyards: Regional plant species lists
- UC IPM: Insectary plants

Plant consciousness

- Regenerative Agriculture Podcast: Unveiling plant consciousness and intelligence

Plant health

- Advancing Eco Agriculture: The plant health pyramid
- Advancing Eco Agriculture: Dr Tom Dykstra: How brix levels impact insect pressure on plants
- Soil Food Web: Dr Tom Dykstra: Why insects avoid healthy plants

Regenerative viticulture

- Advancing Eco Agriculture: Regenerative crop intensive, viticulture
- ARENI Global in conversation: Regenerative agriculture and the future of viticulture with Mimi Casteel
- Grgich Hills Estate, Napa Valley: Cost, chemicals, and cashflow: 3 myths of regenerative farming
- Vidacycle regenerative viticulture: Discovering the power of native insectary plants with Mary Retallack

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